US007298108B2

(12) **United States Patent**
Nagai et al.

(10) **Patent No.: US 7,298,108 B2**
(45) **Date of Patent: Nov. 20, 2007**

(54) **CONTROL SYSTEM FOR ELECTRIC ACTUATOR**

(75) Inventors: **Shigekazu Nagai**, Adachi-ku (JP); **Takeshi Hirose**, Moriya (JP)

(73) Assignee: **SMC Kabushiki Kaisha**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 65 days.

(21) Appl. No.: **11/273,343**

(22) Filed: **Nov. 15, 2005**

(65) **Prior Publication Data**

US 2006/0113940 A1 Jun. 1, 2006

(30) **Foreign Application Priority Data**

Nov. 29, 2004 (JP) 2004-344871

(51) **Int. Cl.**
F16H 25/20 (2006.01)
B23Q 5/28 (2006.01)
H02K 7/06 (2006.01)

(52) **U.S. Cl.** **318/469**; 318/468; 192/141; 192/143; 310/80; 74/89; 74/89.23

(58) **Field of Classification Search** .... None
See application file for complete search history.

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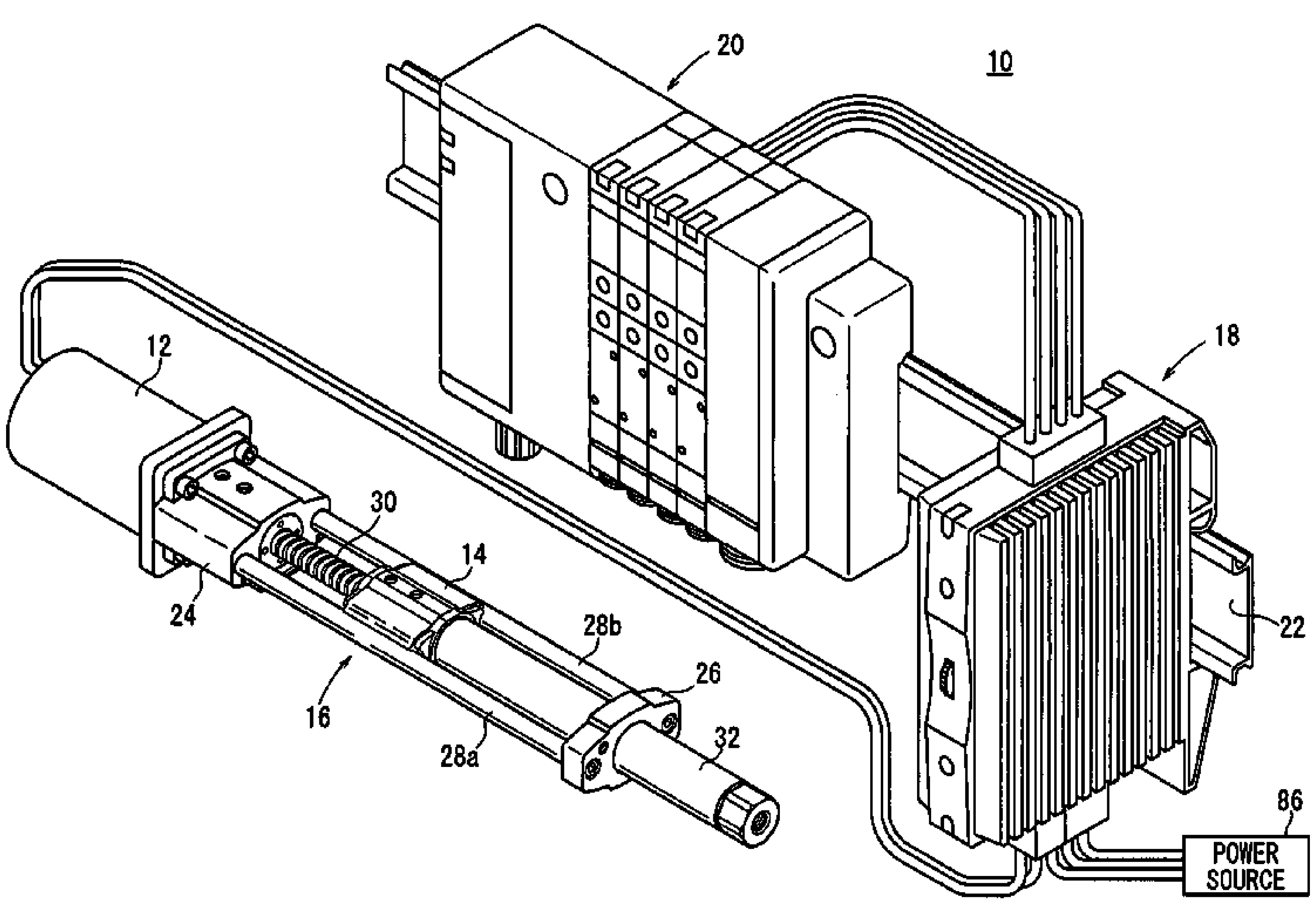
Primary Examiner—Lincoln Donovan
Assistant Examiner—Eduardo Colon Santana
(74) *Attorney, Agent, or Firm*—Paul A. Guss

(57) **ABSTRACT**

A driver comprises a direction-switching means which switches a rotation direction of a rotary driving source based on a direction instruction signal, a current amplifier/limiter which converts a voltage outputted from the direction-switching means into a corresponding current and which limits the current to a preset reference current I_{MAX} (threshold value), a current sensor which detects the current supplied to the rotary driving source, and a current loop which feeds back a detection signal supplied from the current sensor to an upstream side of the current amplifier/limiter.

7 Claims, 42 Drawing Sheets



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JP	2002-219625			8/2002
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JP	2006-22950			1/2006

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FIG. 1

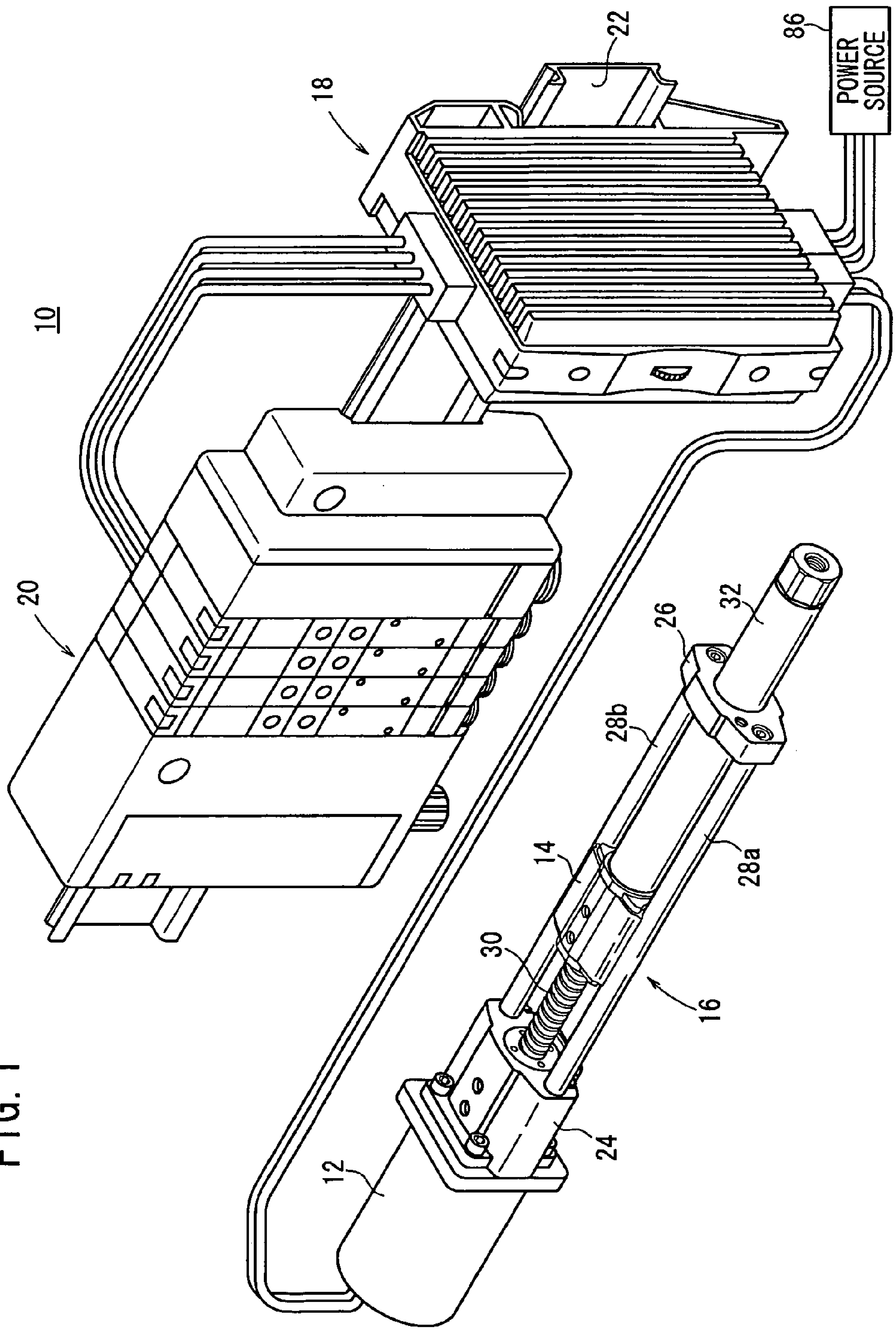


FIG. 2

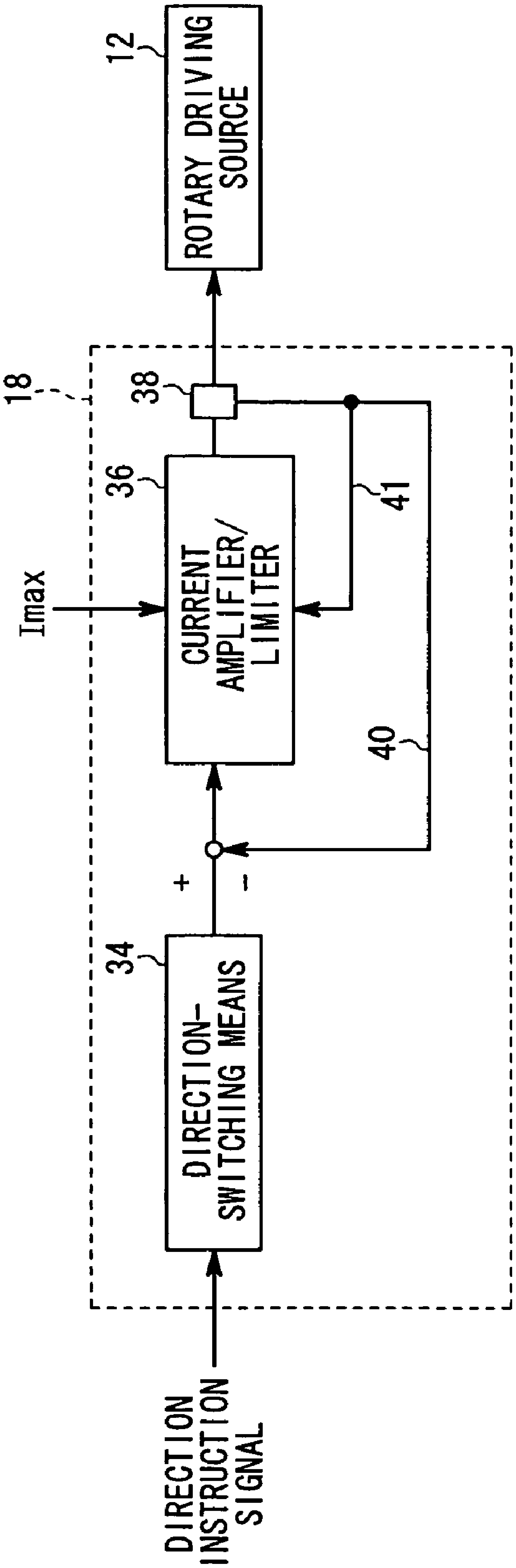
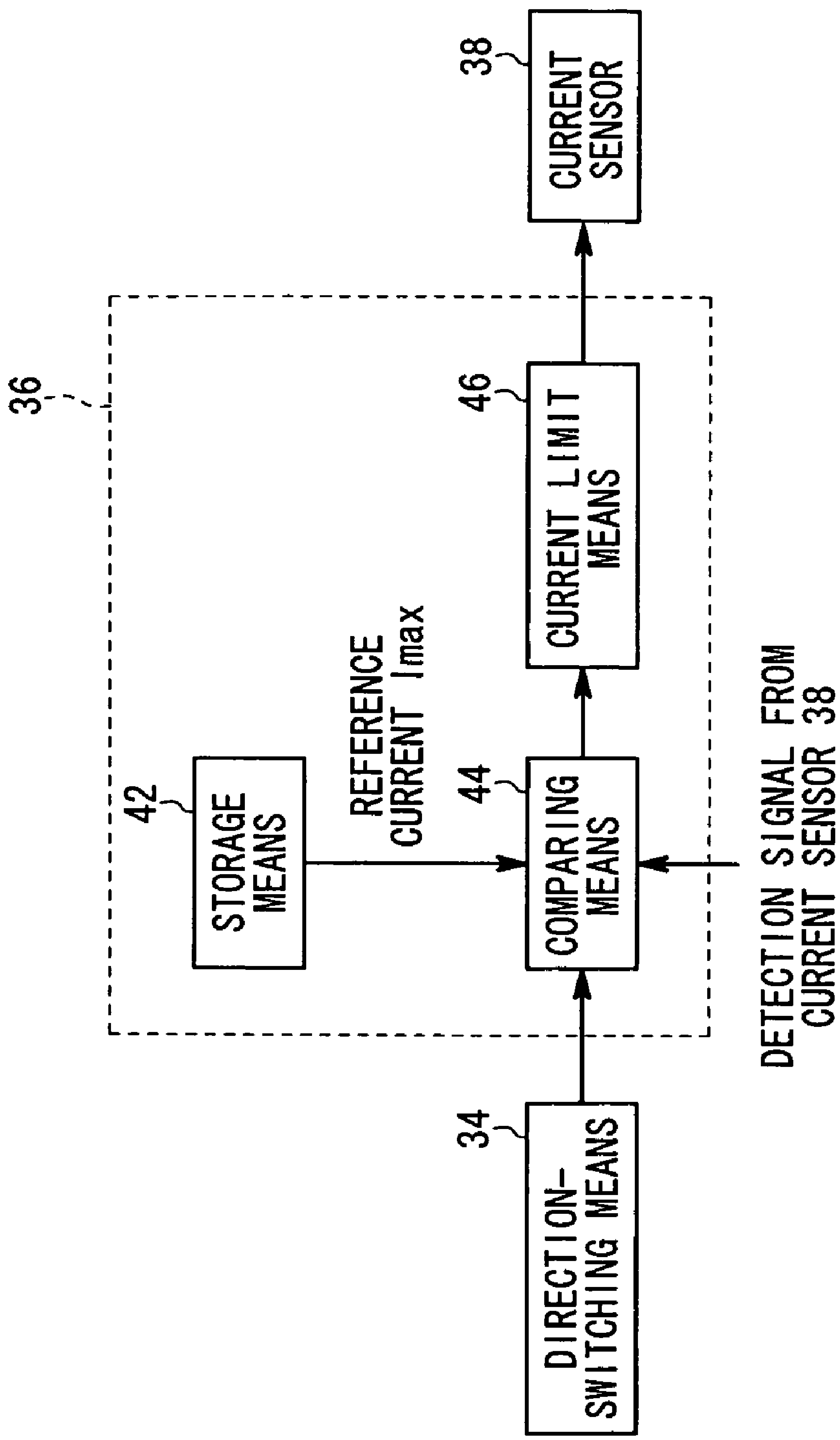

12
ROTARY DRIVING SOURCE
18
38
36
CURRENT AMPLIFIER/ LIMITER
Imax
41
40
+
-
34
DIRECTION-SWITCHING MEANS
DIRECTION INSTRUCTION SIGNAL

FIG. 3



38
CURRENT SENSOR
36
46
CURRENT LIMIT MEANS
42
STORAGE MEANS
REFERENCE CURRENT Imax
44
COMPARING MEANS
DETECTION SIGNAL FROM CURRENT SENSOR 38
34
DIRECTION-SWITCHING MEANS

FIG. 4

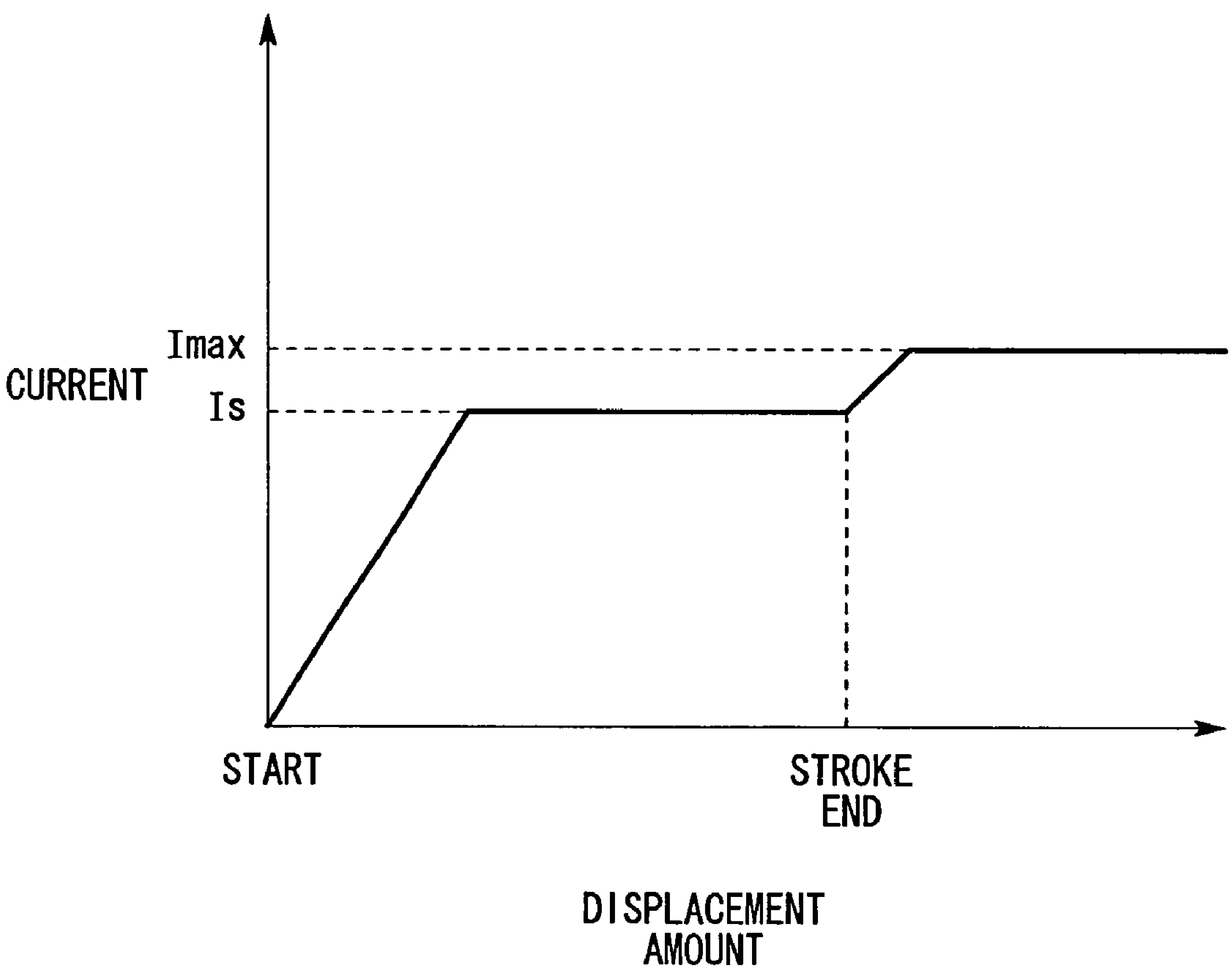


FIG. 5

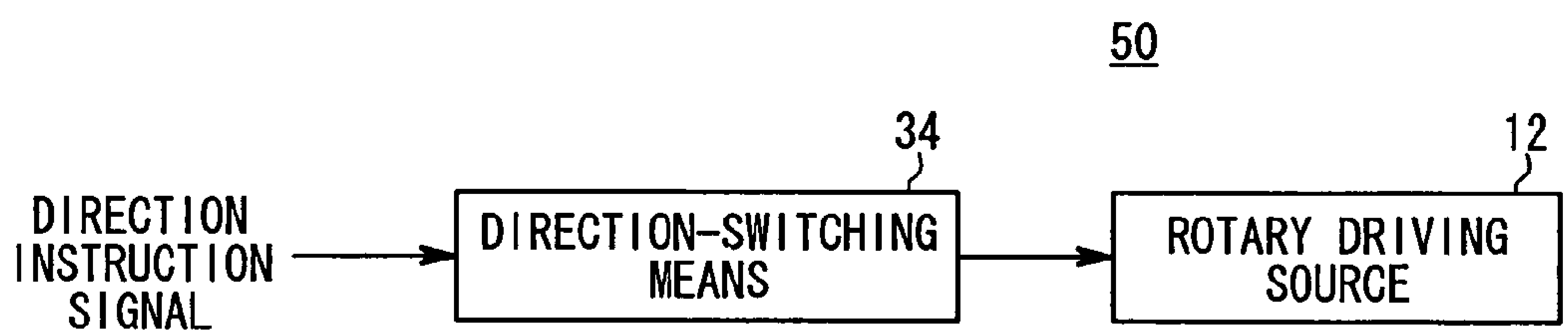

50
34
12
DIRECTION
INSTRUCTION
SIGNAL
DIRECTION-SWITCHING
MEANS
ROTARY DRIVING
SOURCE

FIG. 6

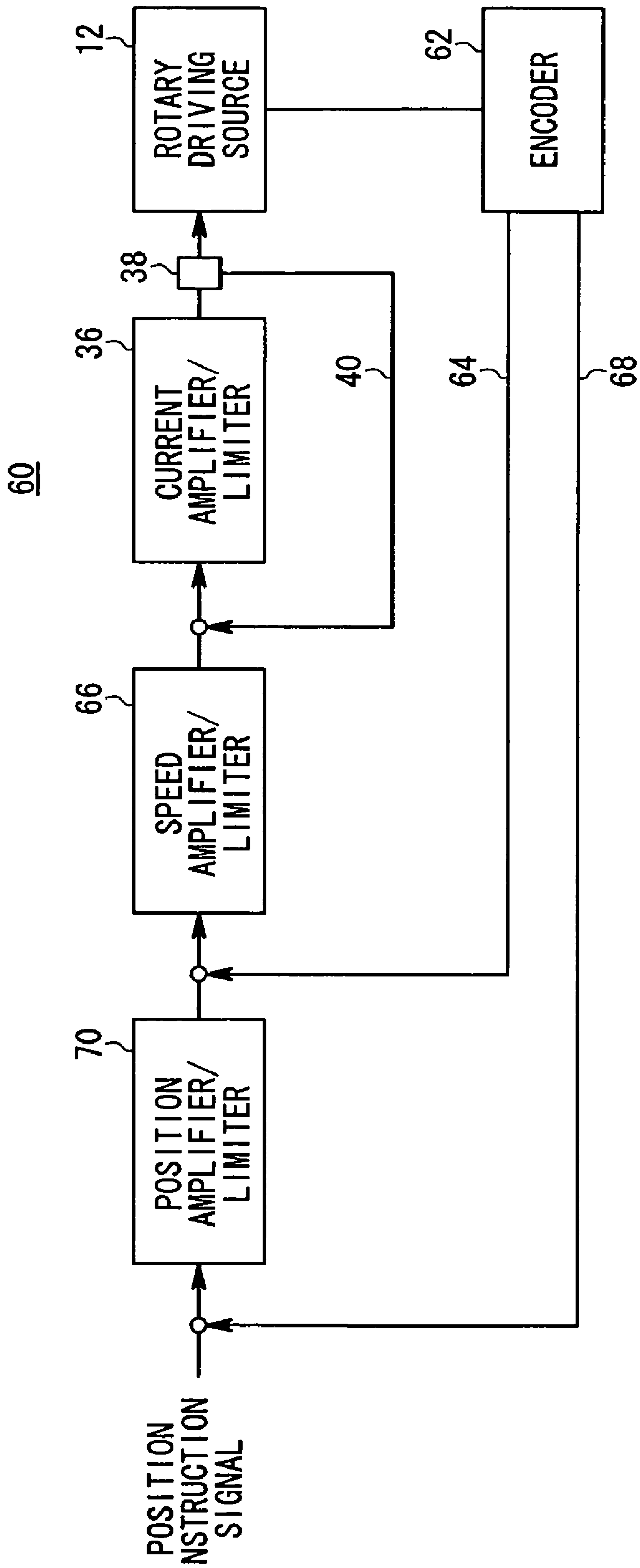

60
ROTARY DRIVING SOURCE
12
ENCODER
62
38
36
CURRENT AMPLIFIER/ LIMITER
40
64
68
66
SPEED AMPLIFIER/ LIMITER
70
POSITION AMPLIFIER/ LIMITER
POSITION INSTRUCTION SIGNAL

FIG. 7

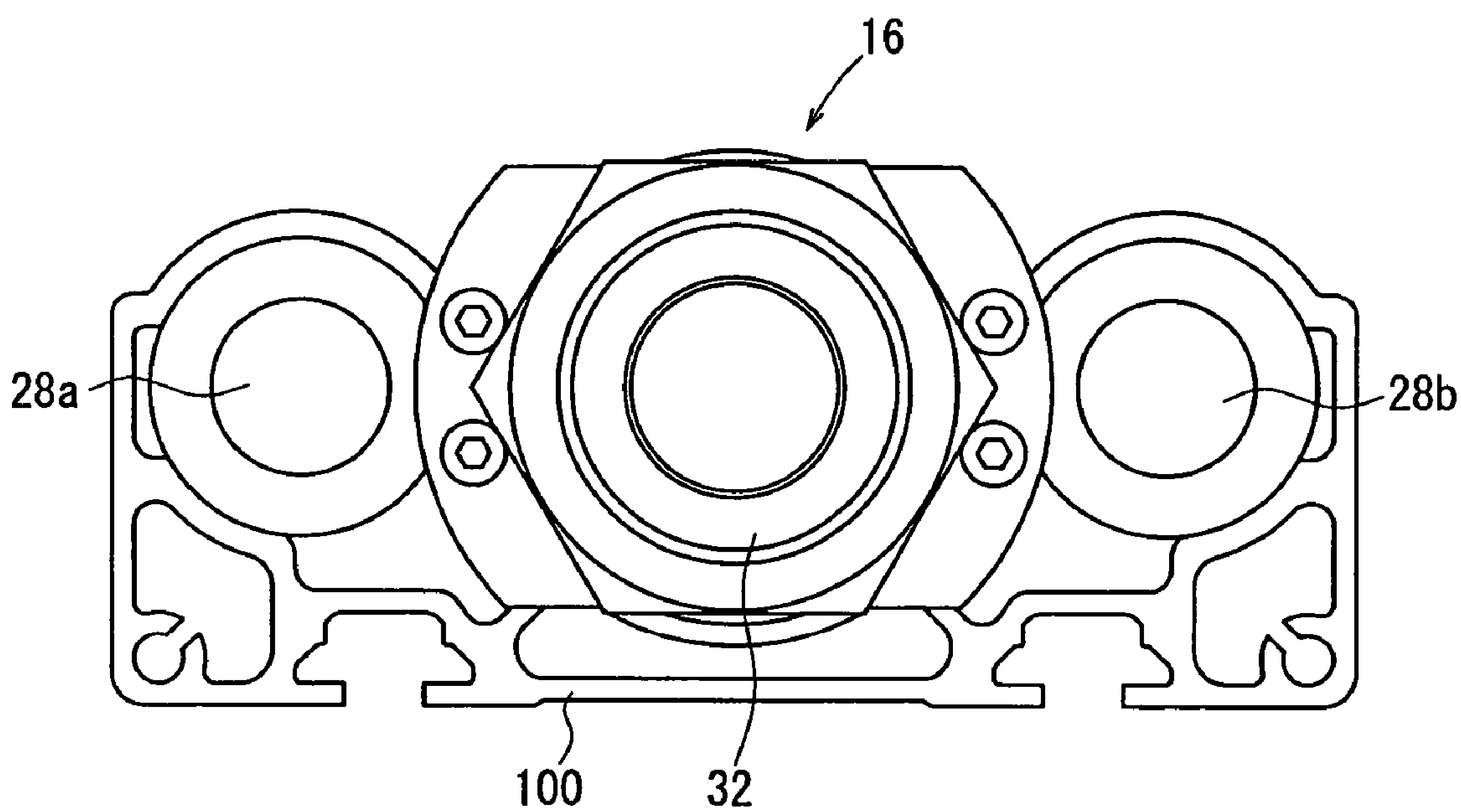


FIG. 8

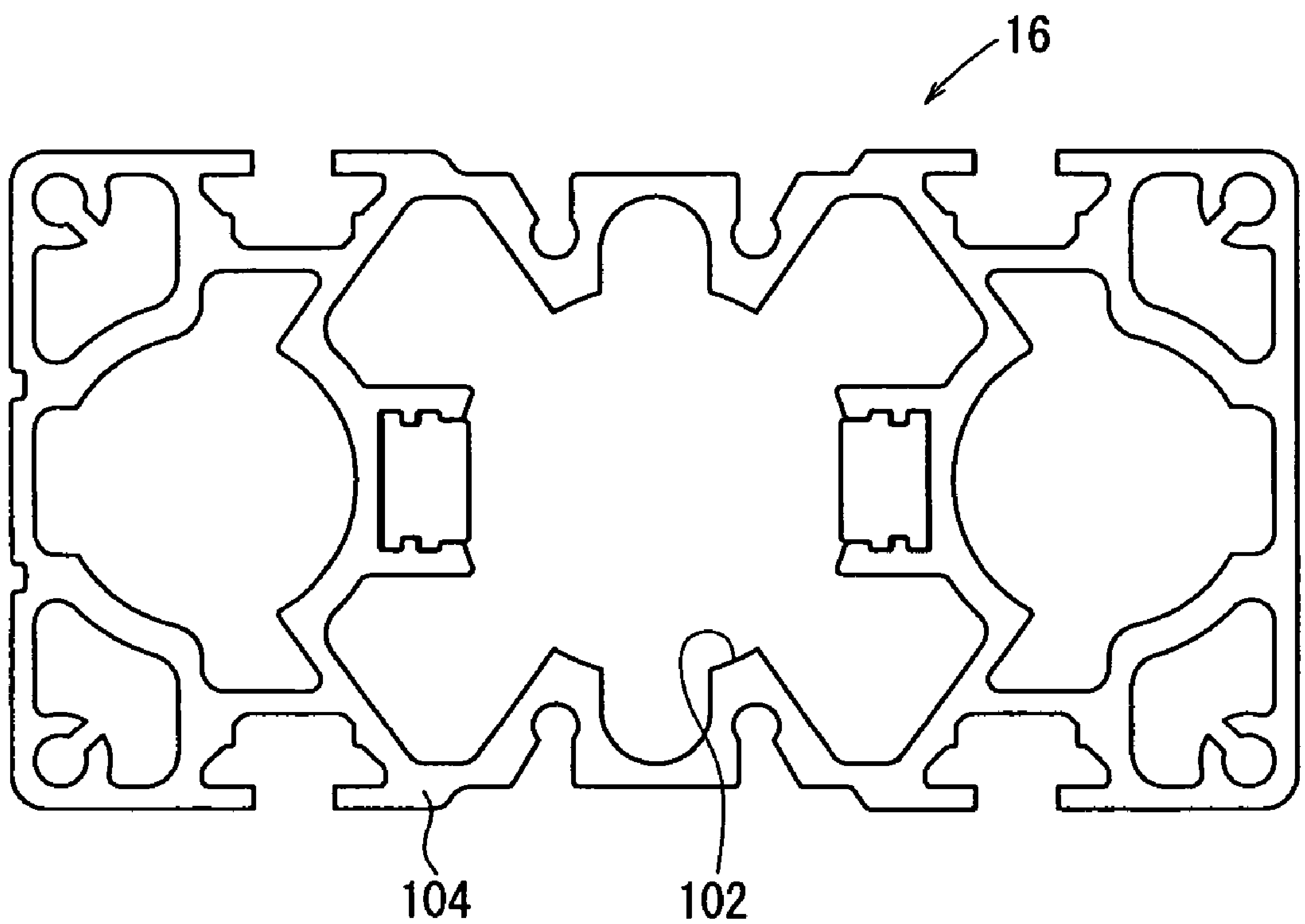
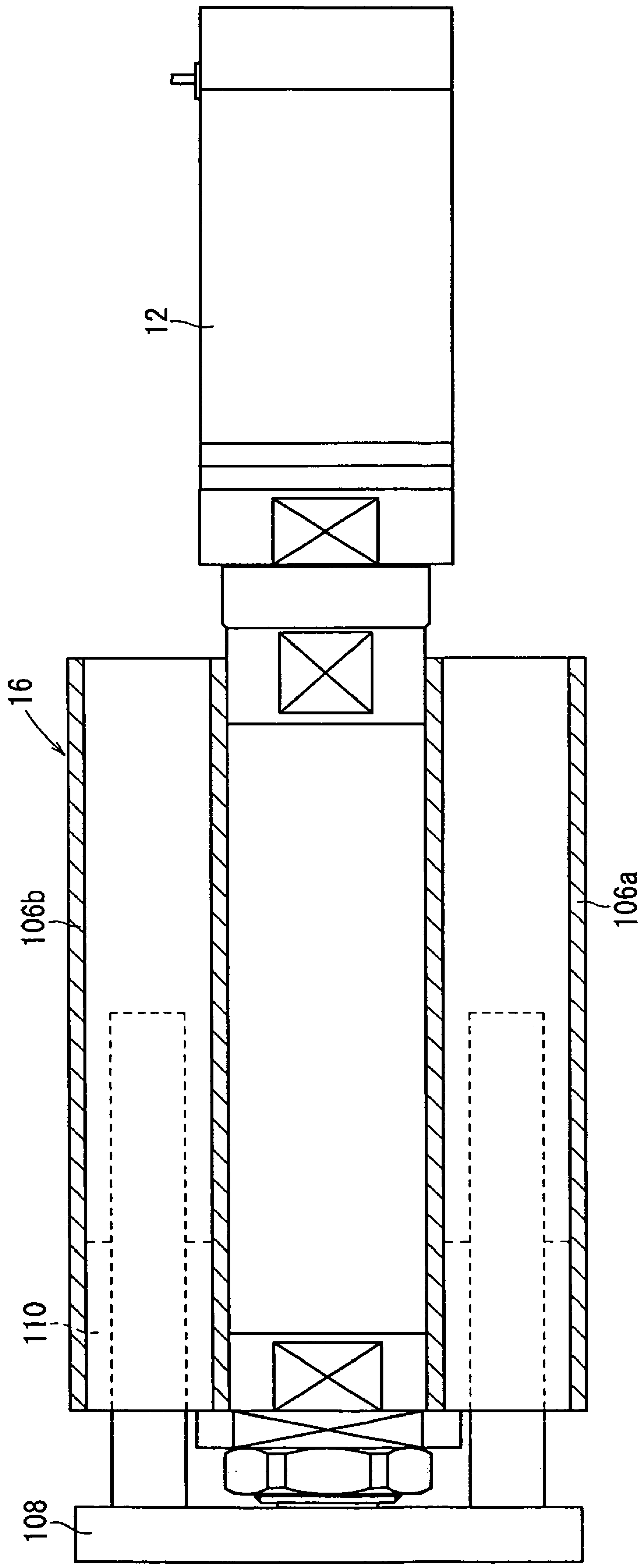


FIG. 9



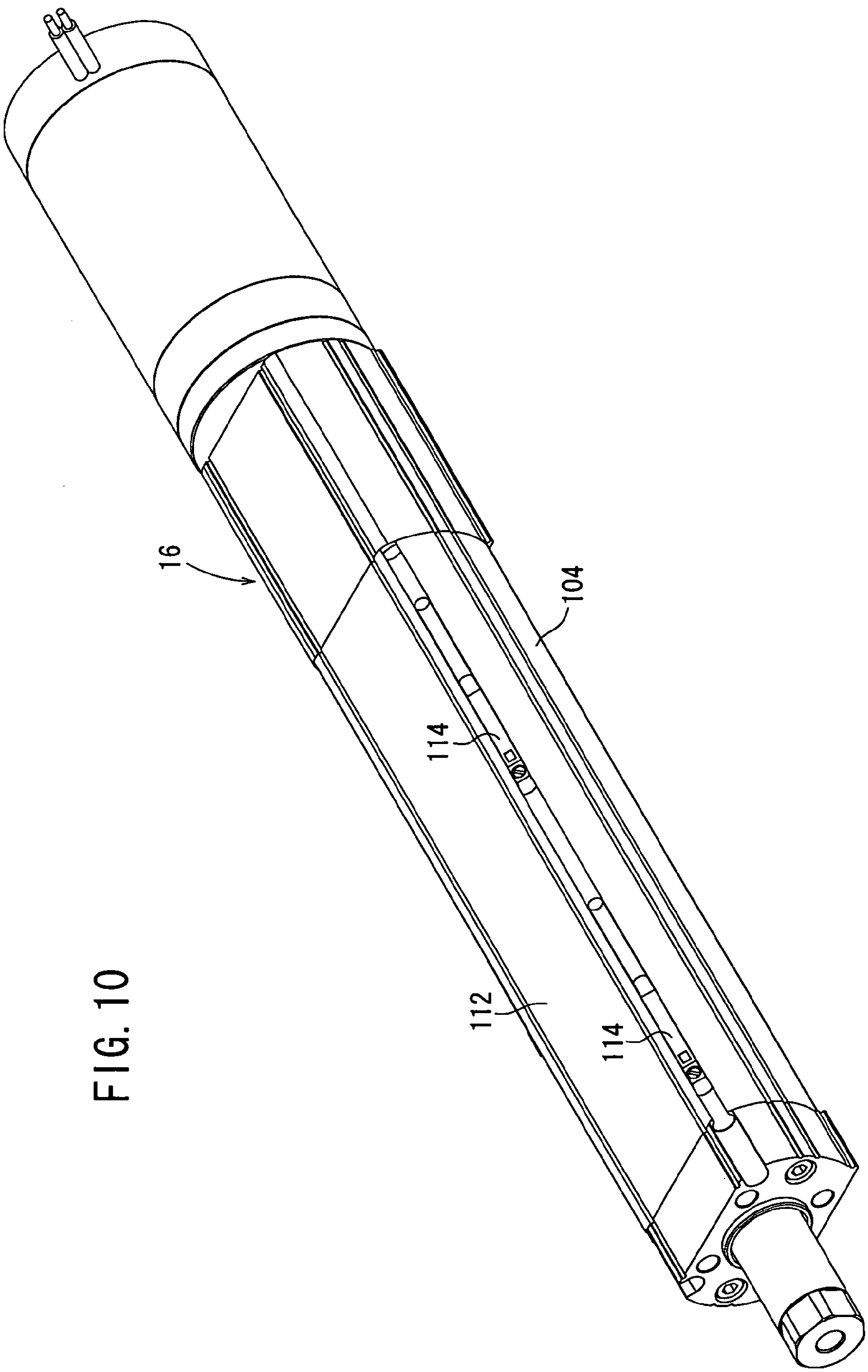


FIG. 10

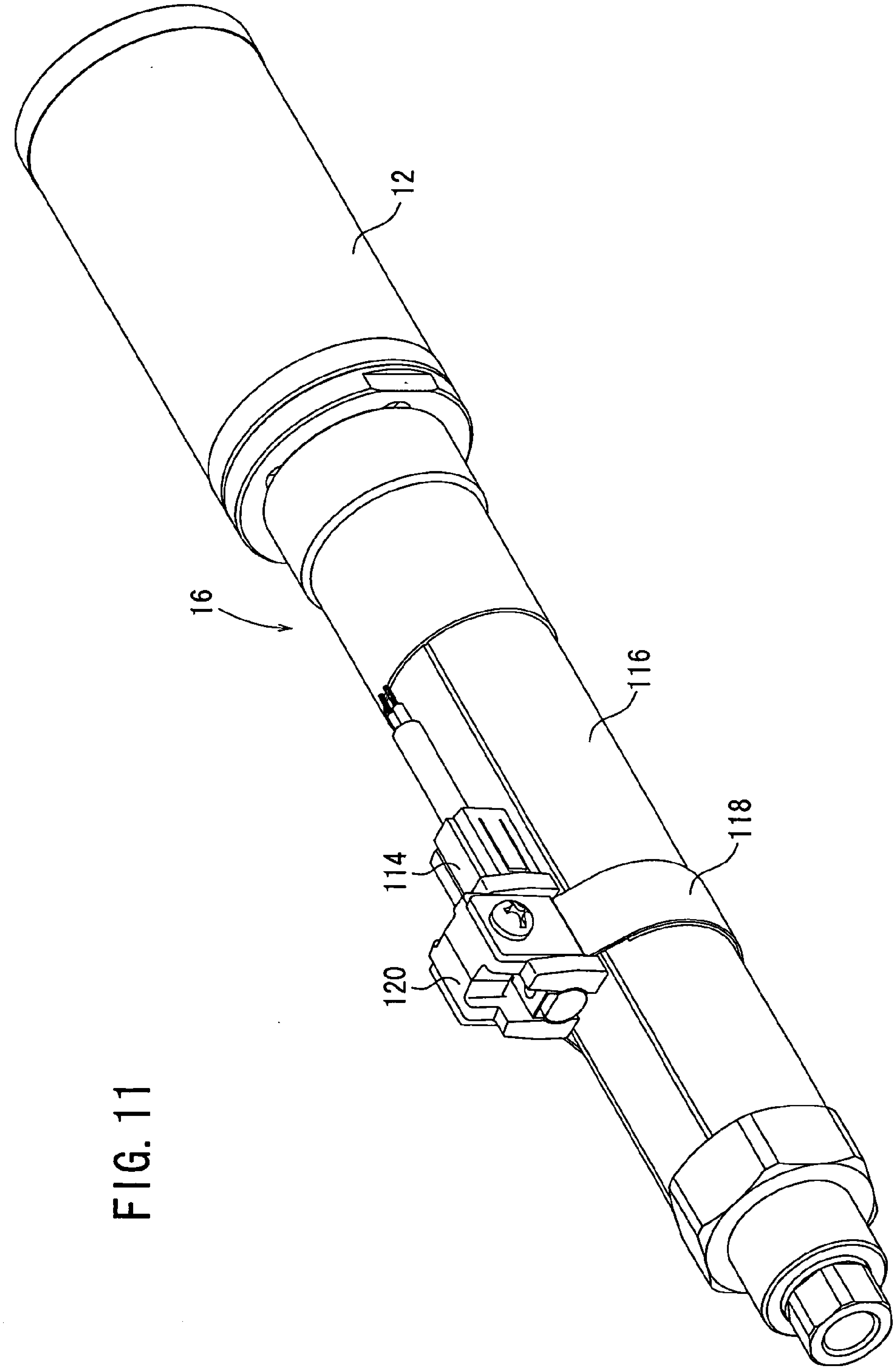


FIG. 11

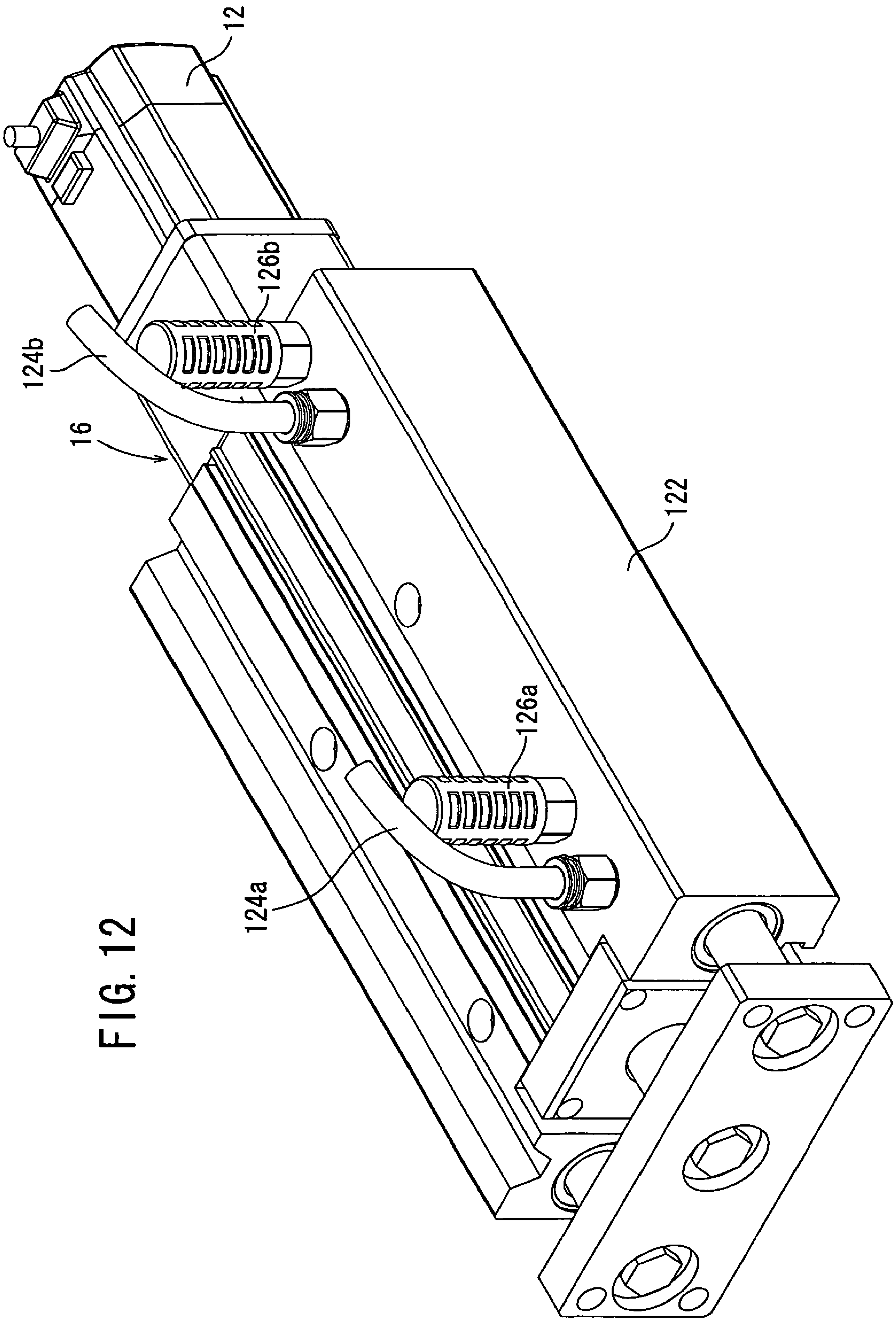


FIG. 12

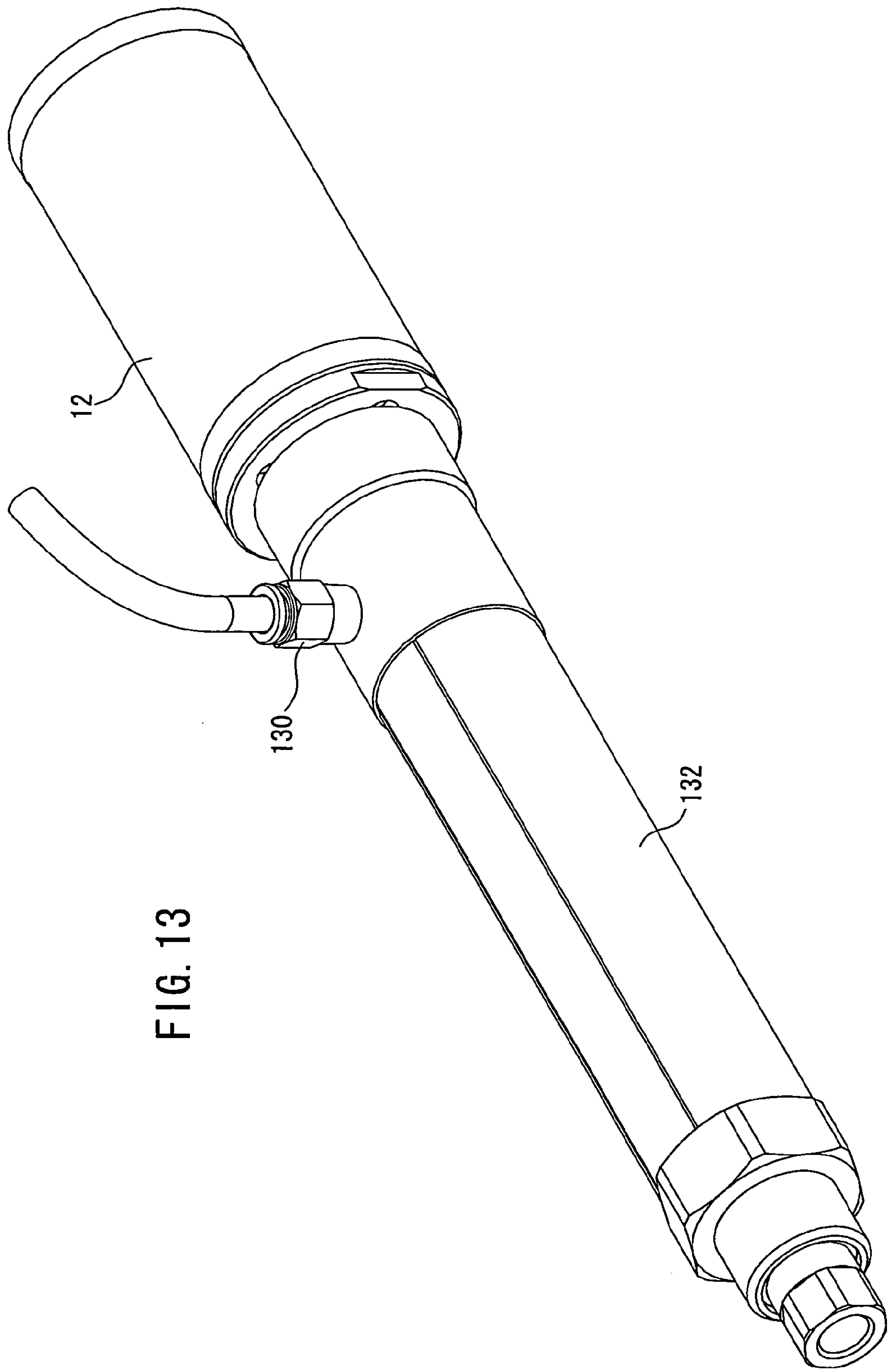
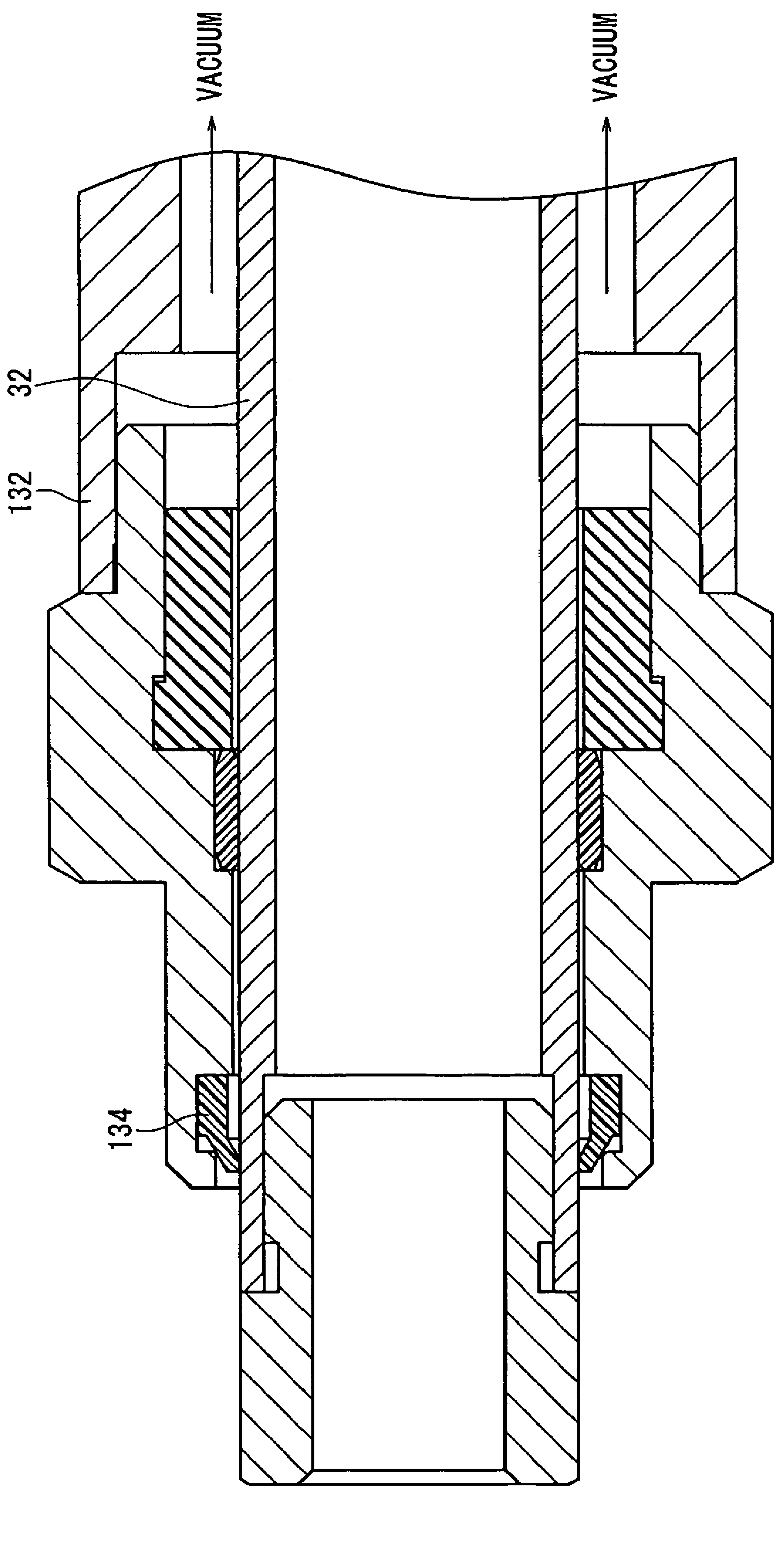


FIG. 13

FIG. 14



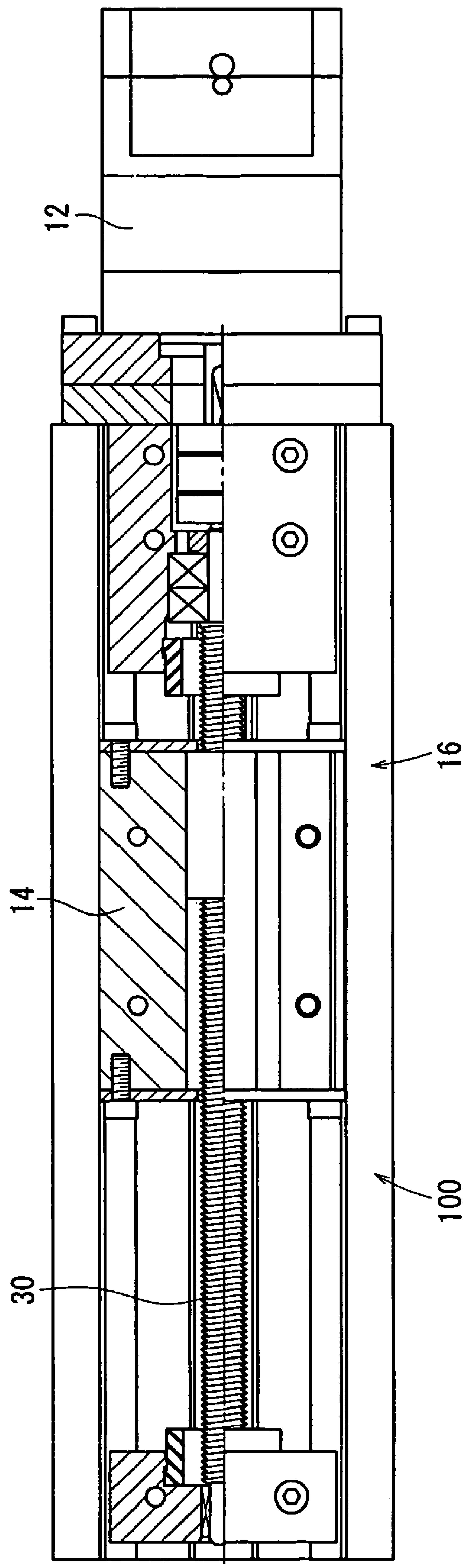


FIG. 15

FIG. 16

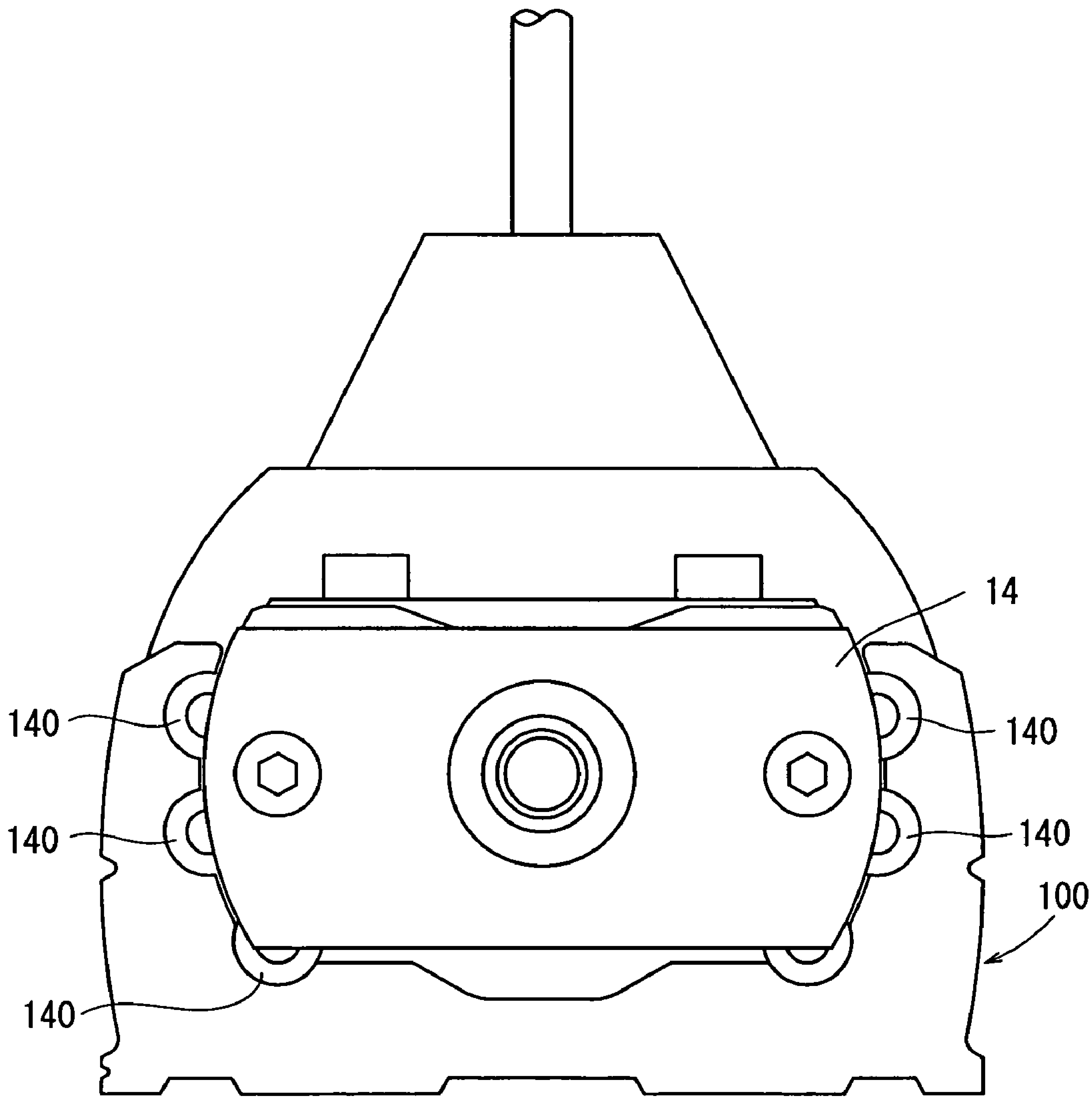
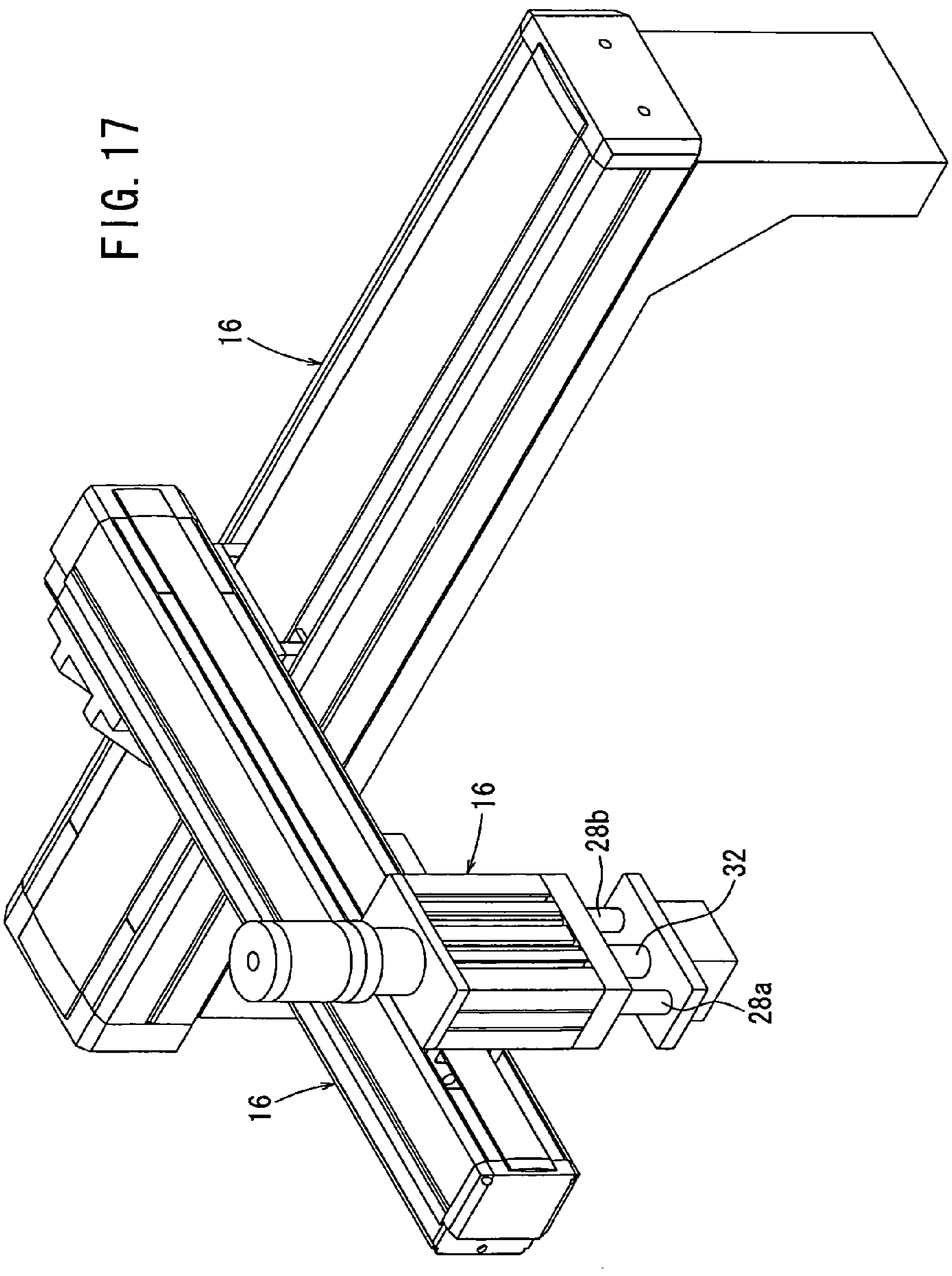


FIG. 17



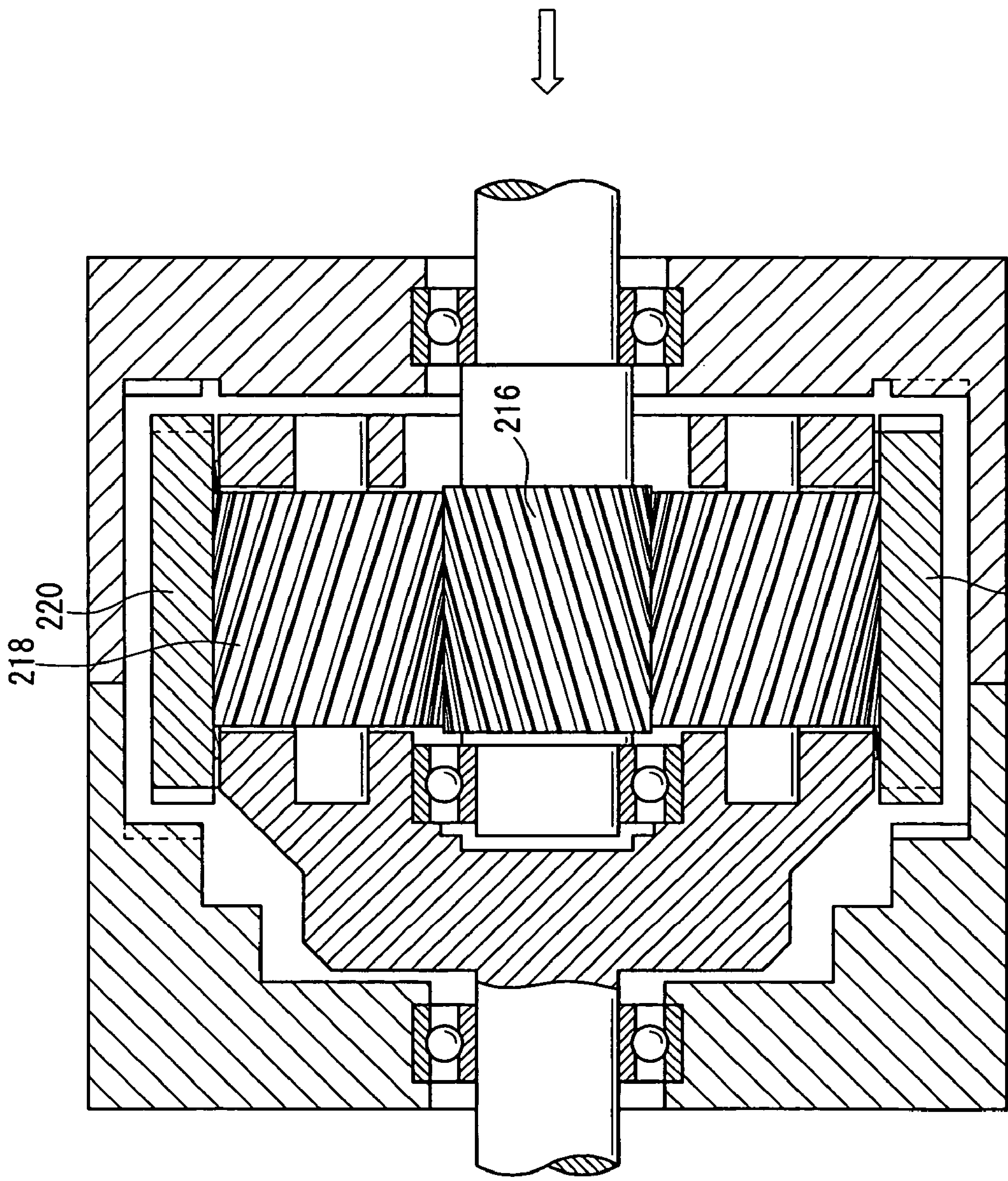


FIG. 18

FIG. 19A

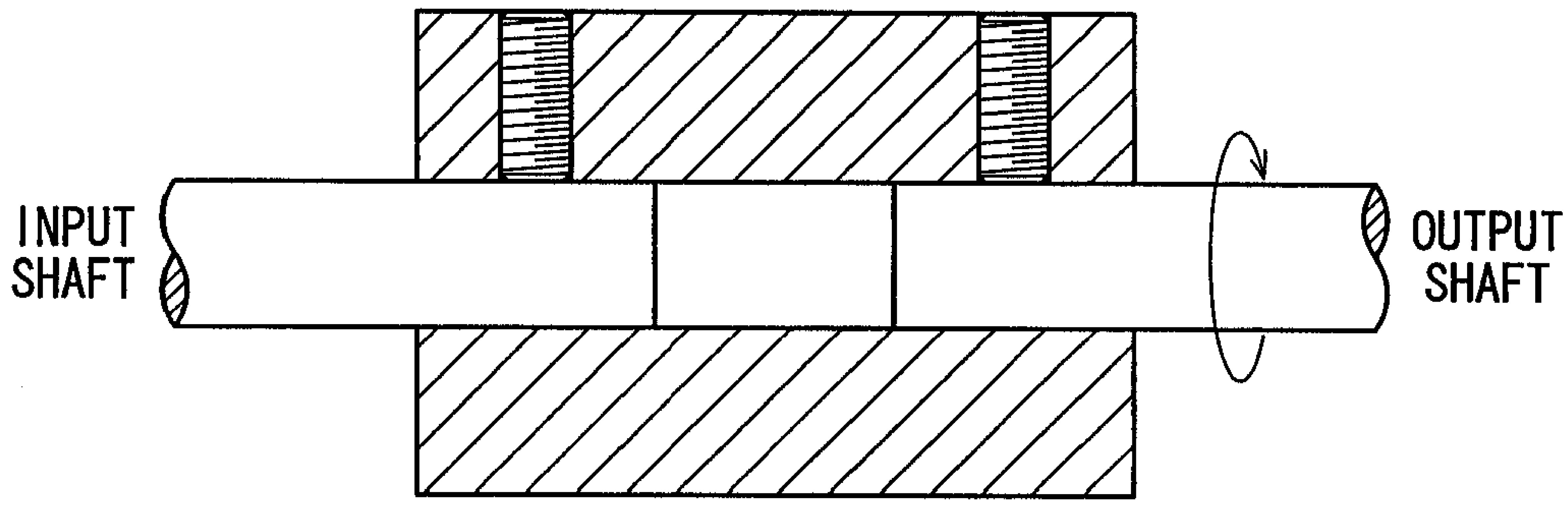


FIG. 19B

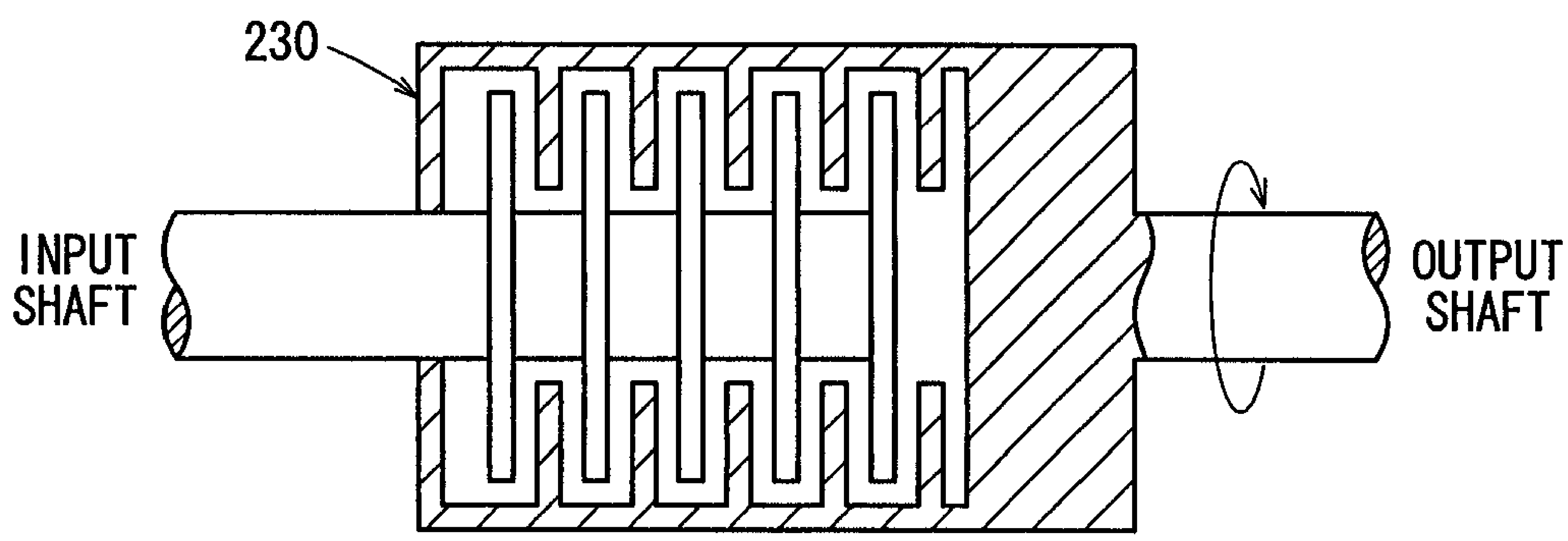
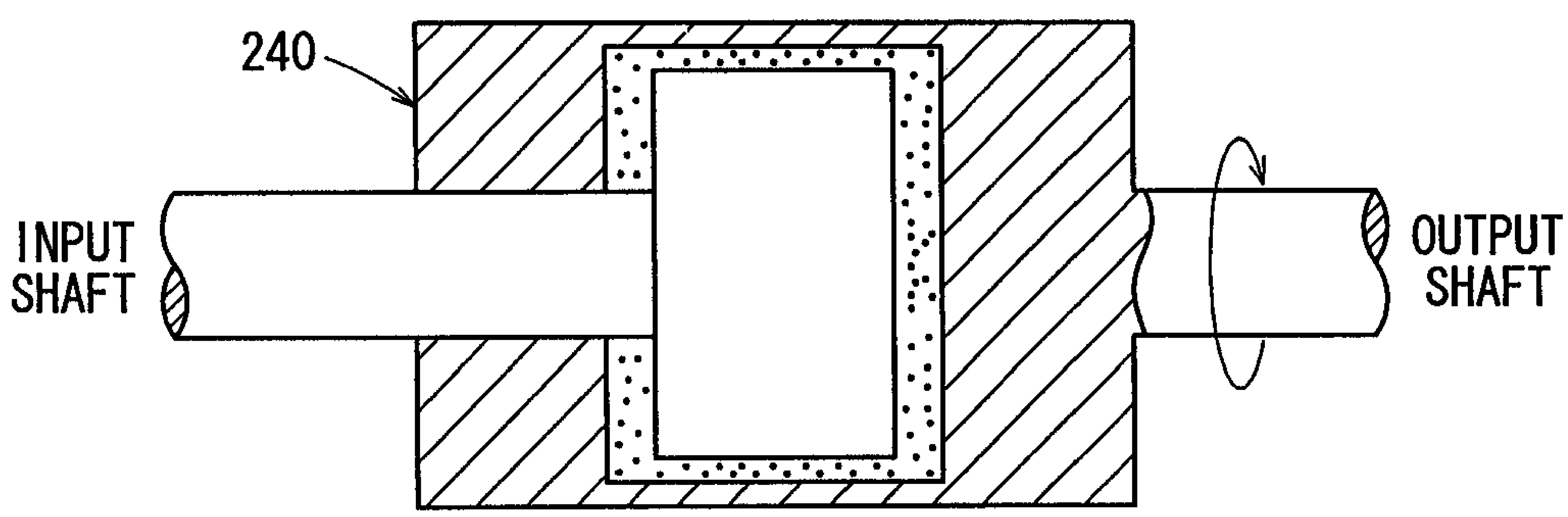


FIG. 19C



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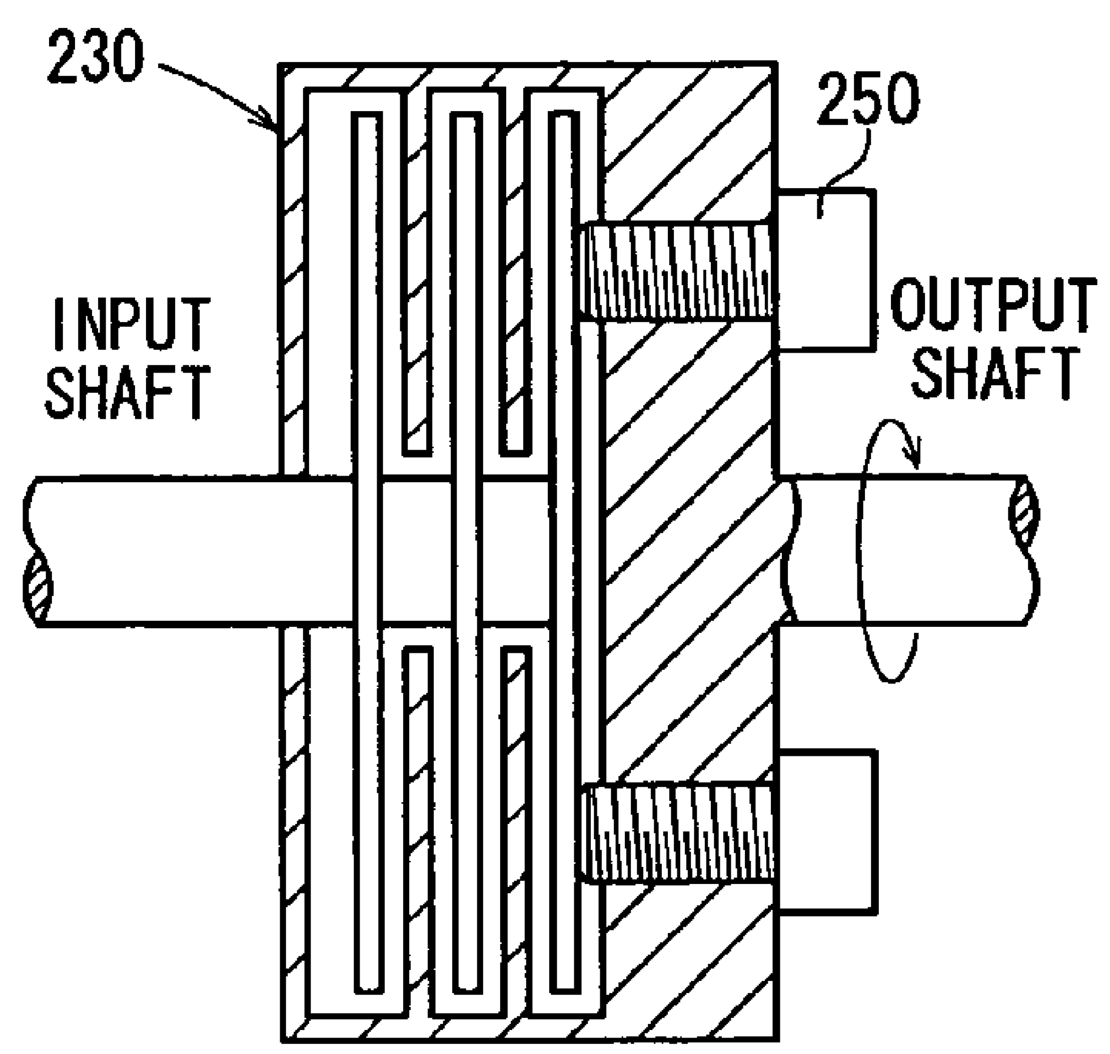


FIG. 20B

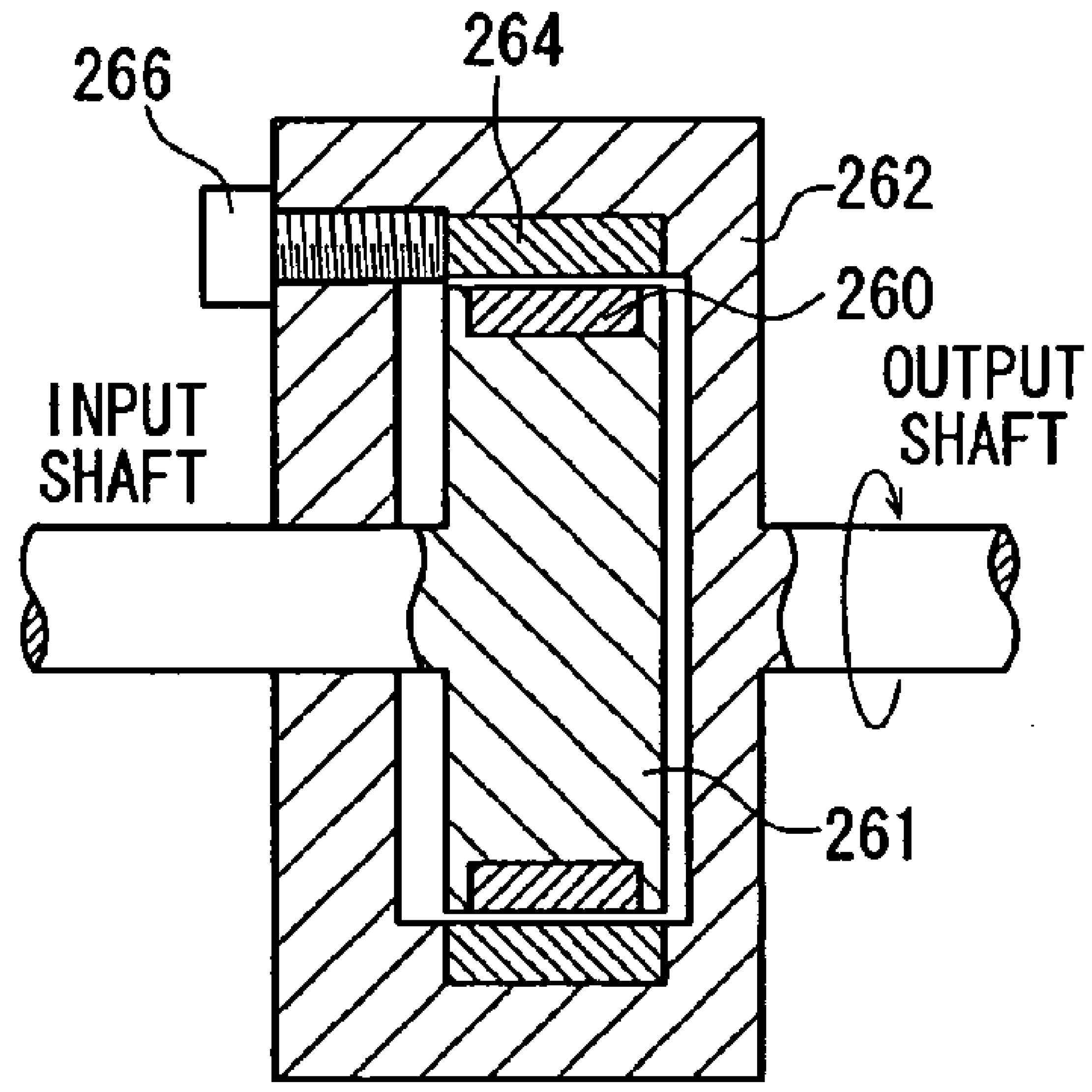


FIG. 20C

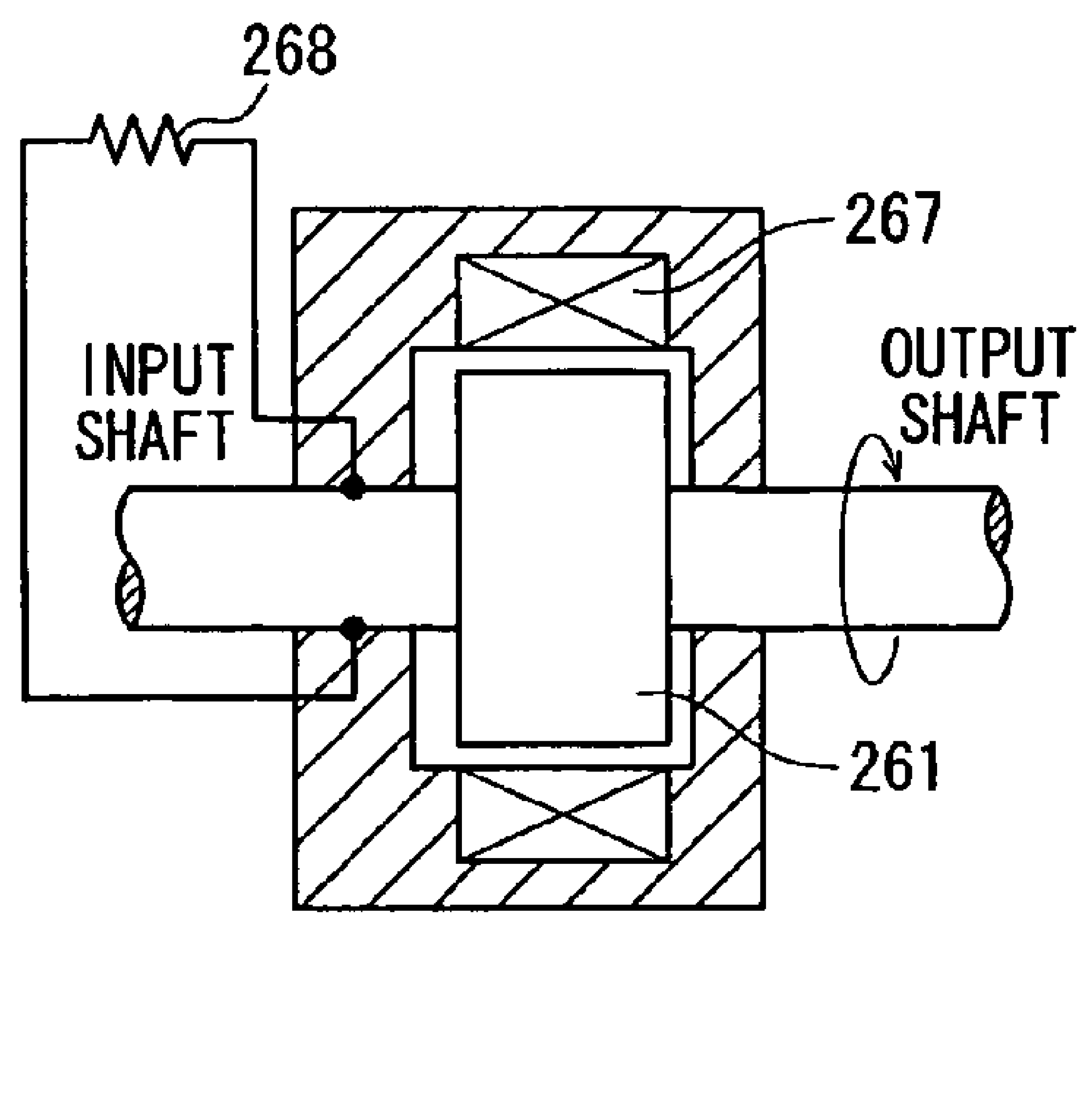
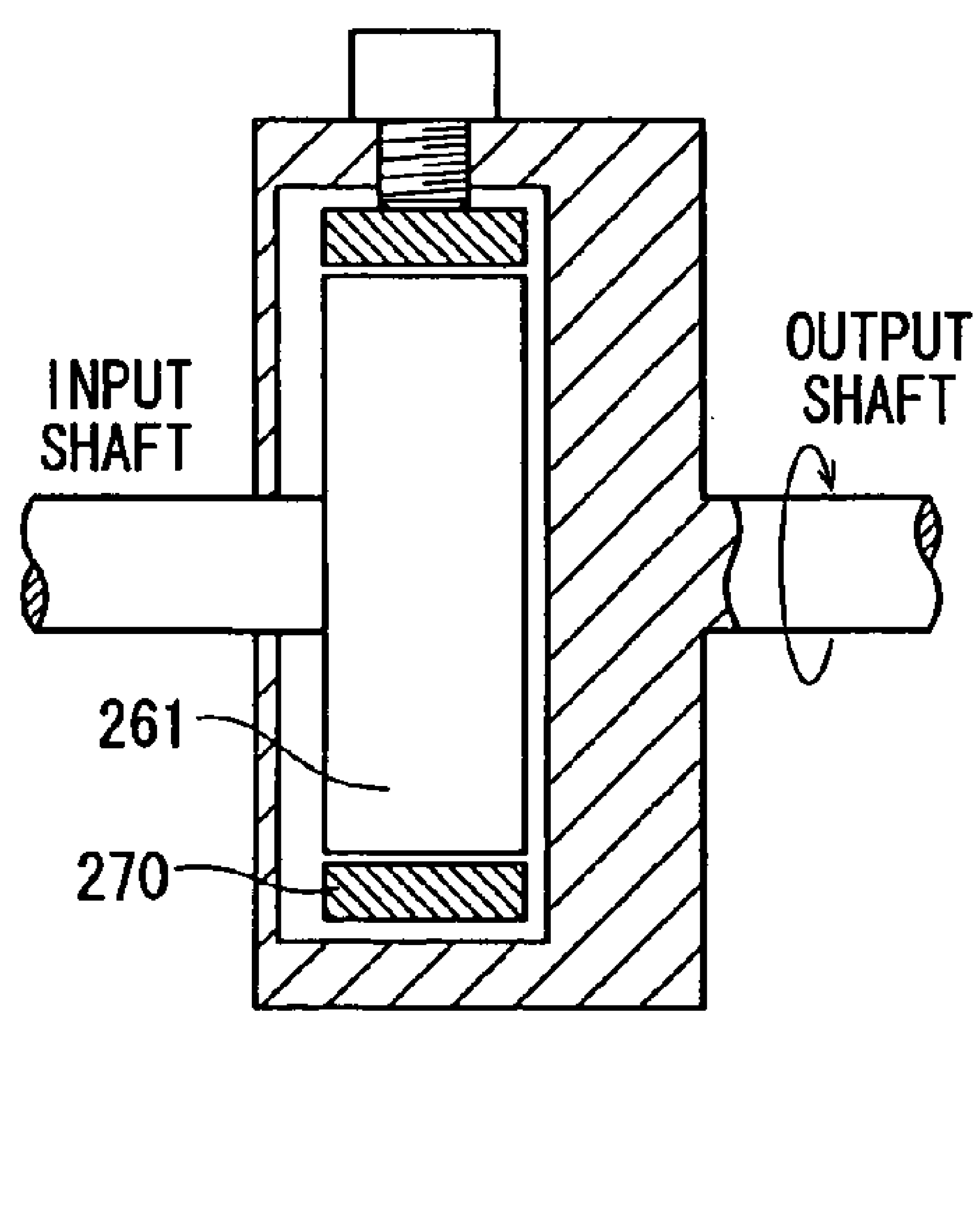


FIG. 20D



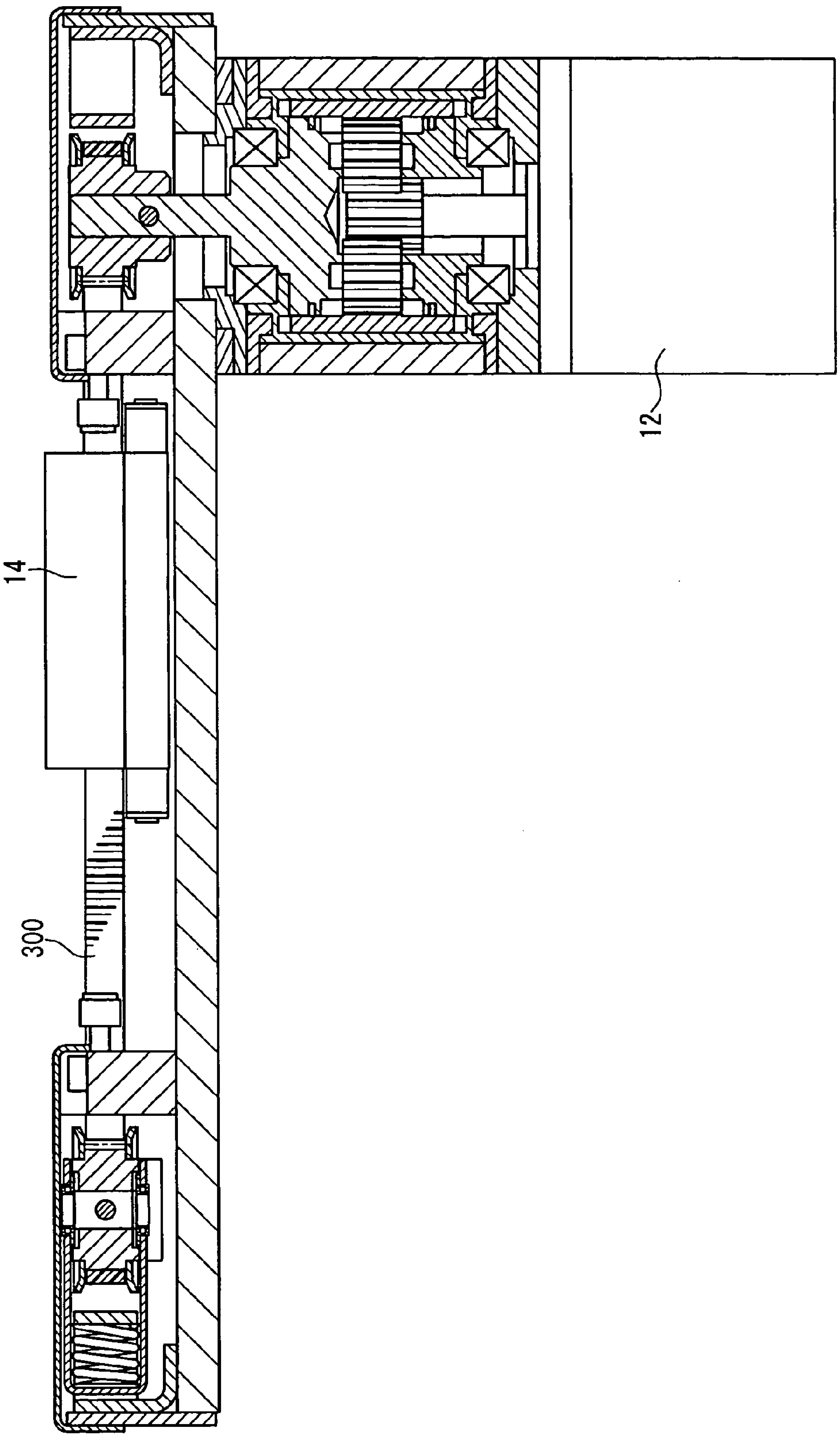


FIG. 21

FIG. 22

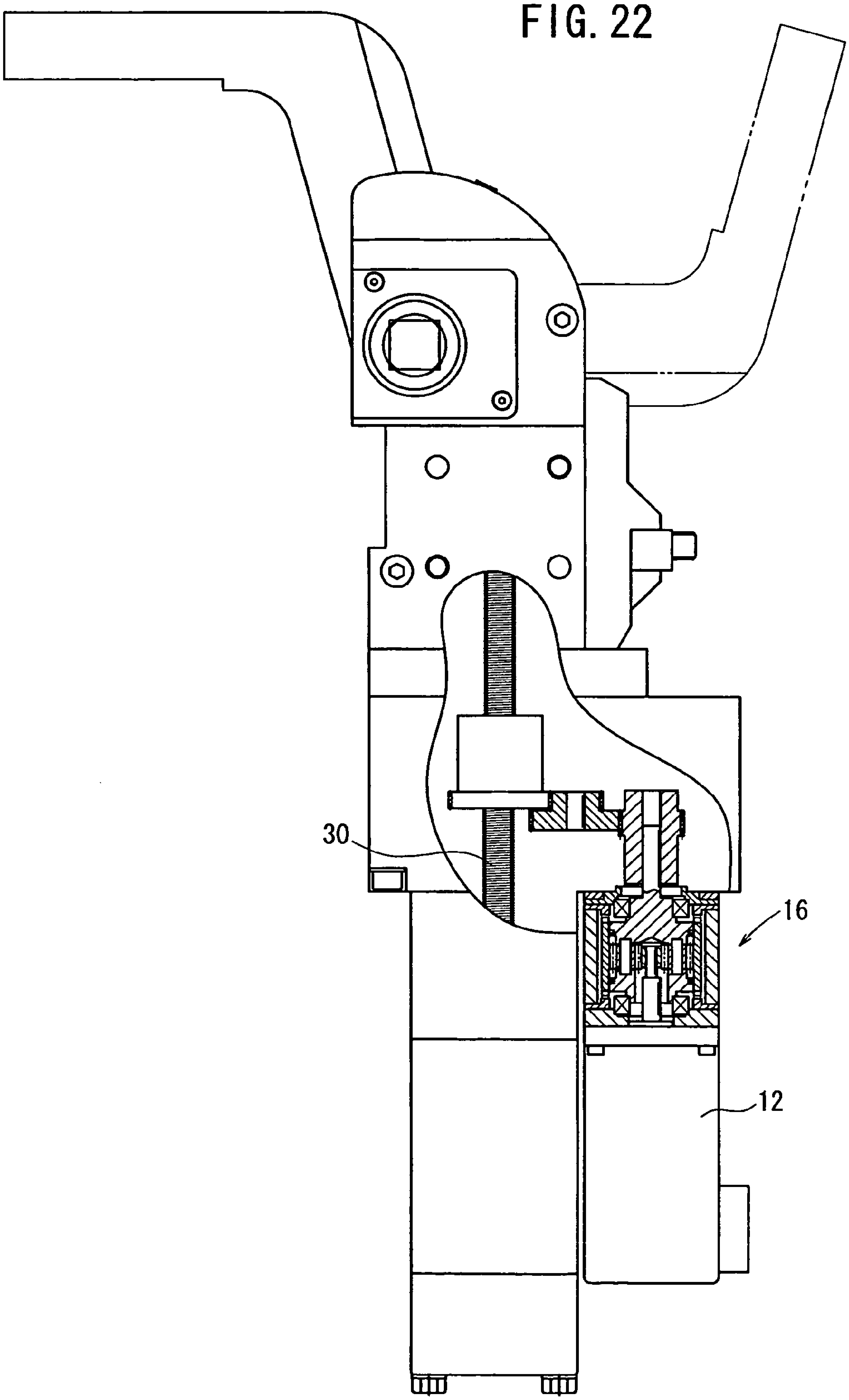


FIG. 23

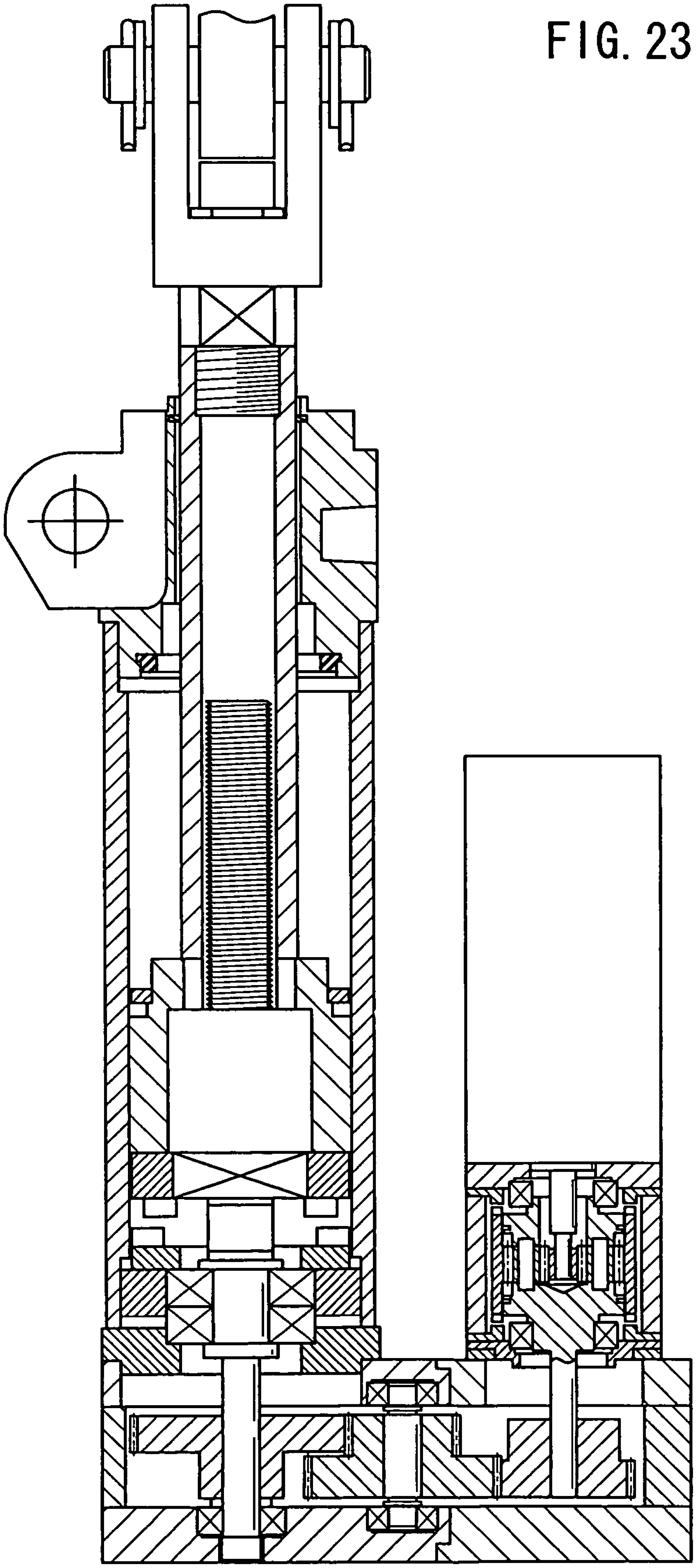
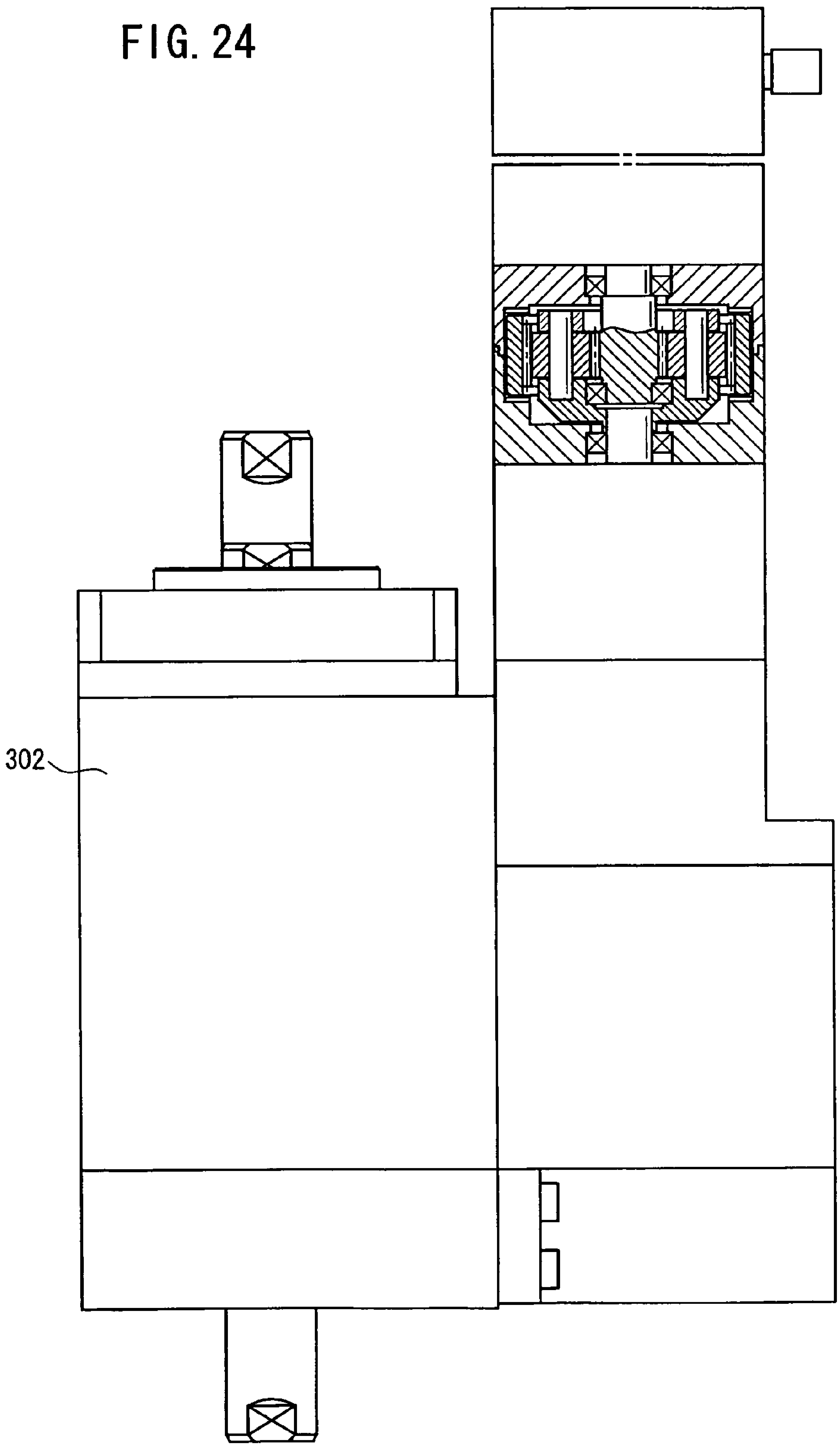


FIG. 24



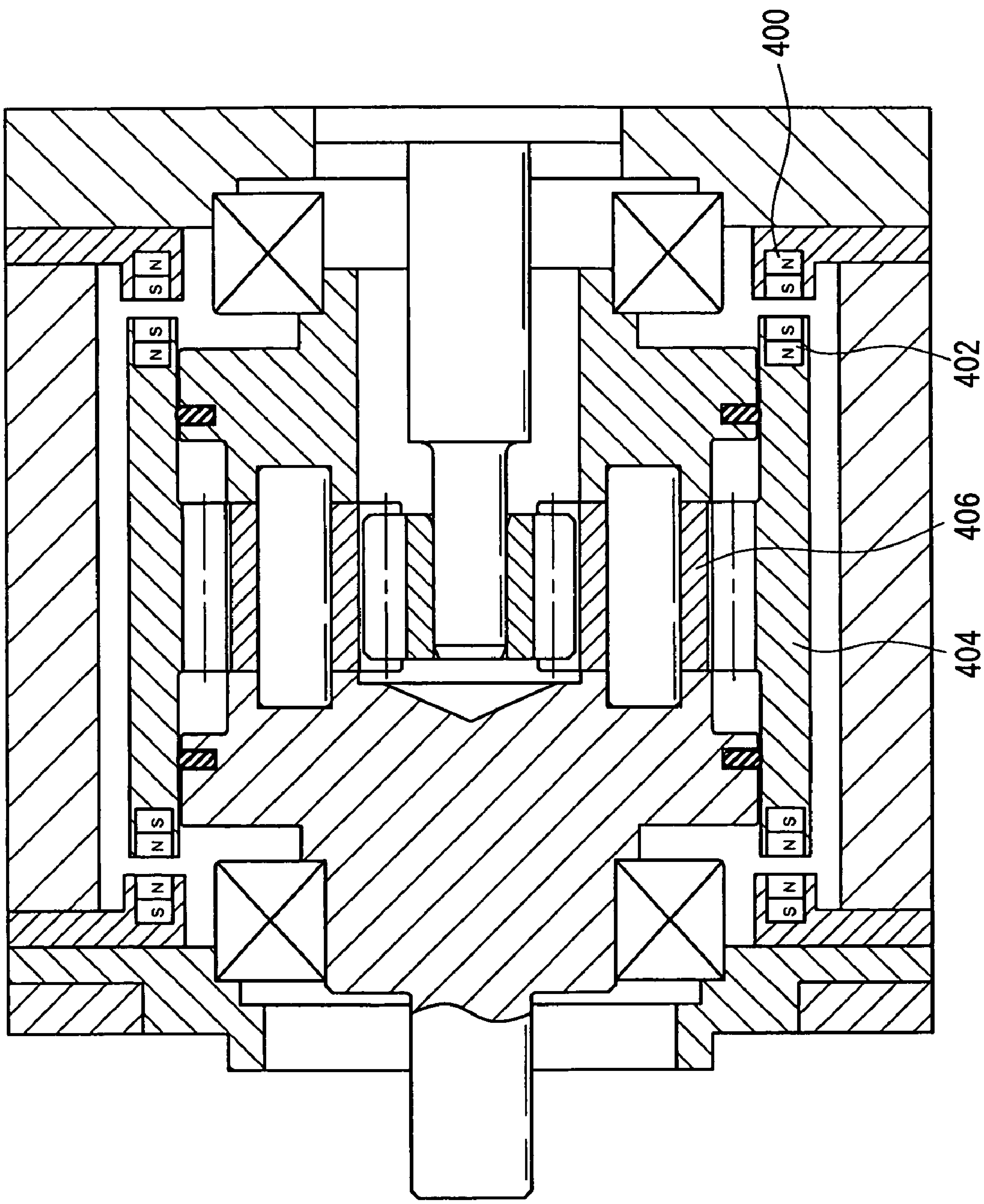
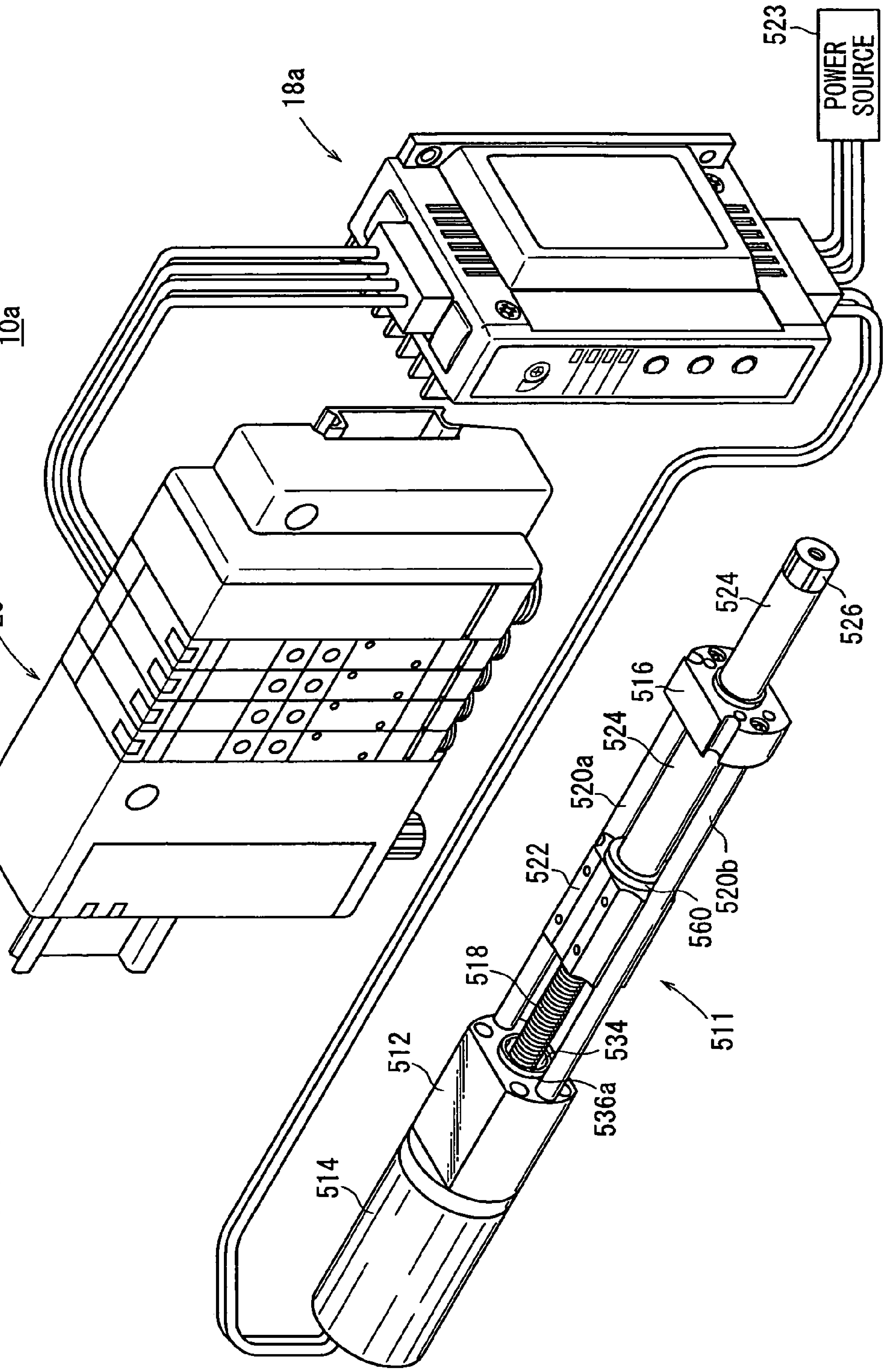


FIG. 25

FIG. 26


10a
18a
20
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POWER SOURCE
524
526
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520b
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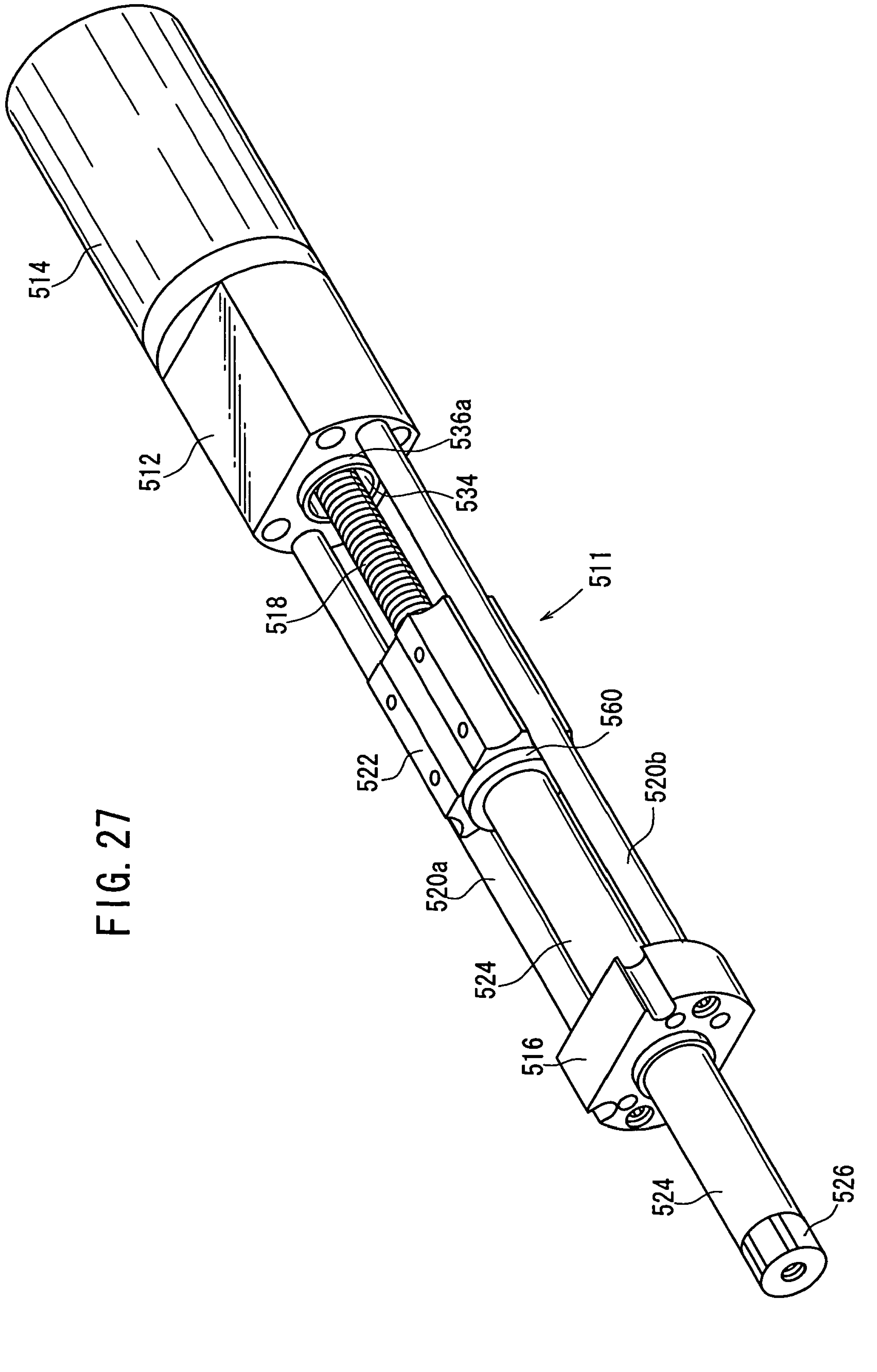
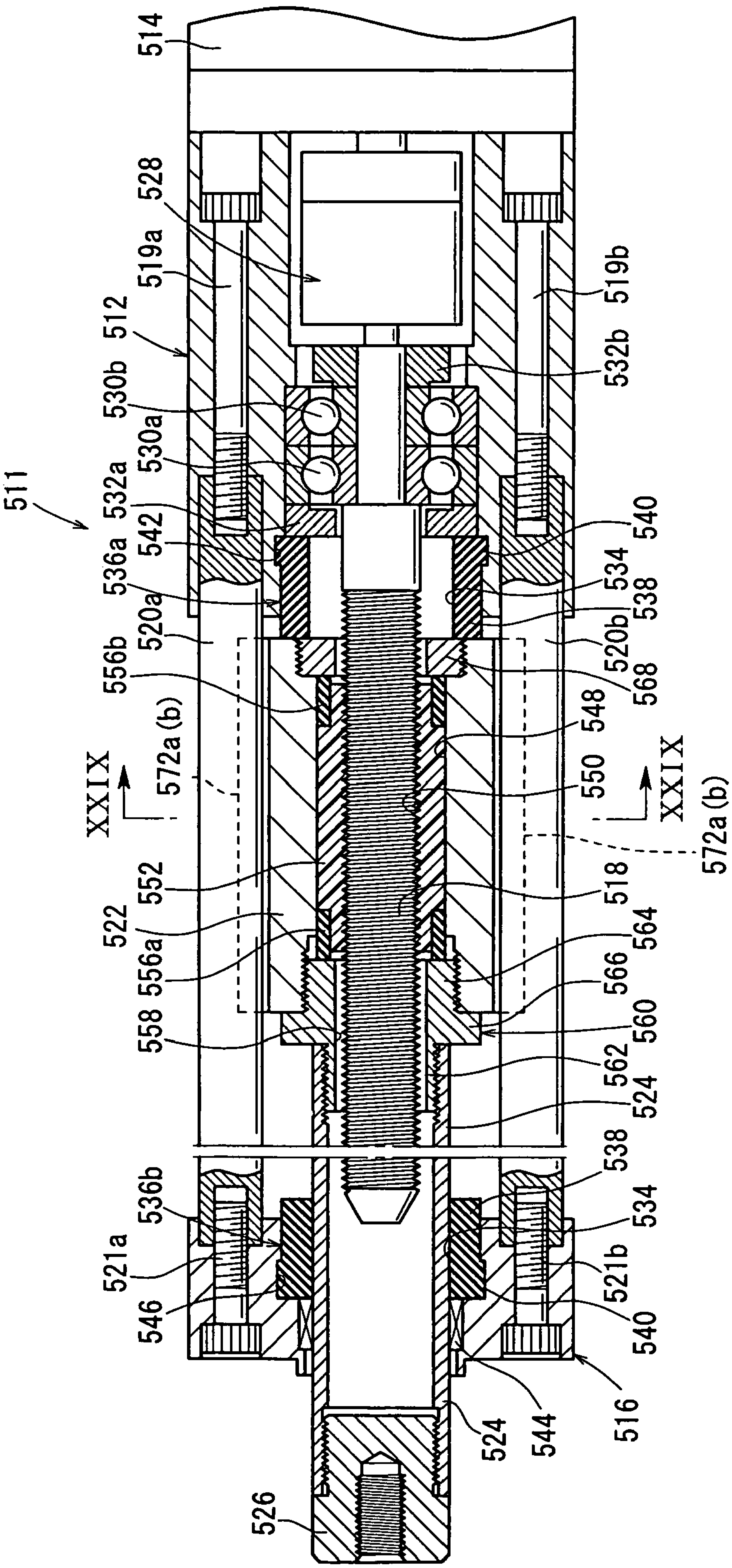


FIG. 27

FIG. 28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XXIX
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558
511
519b
532b
540
534
538
520b
568
548
550
XXIX
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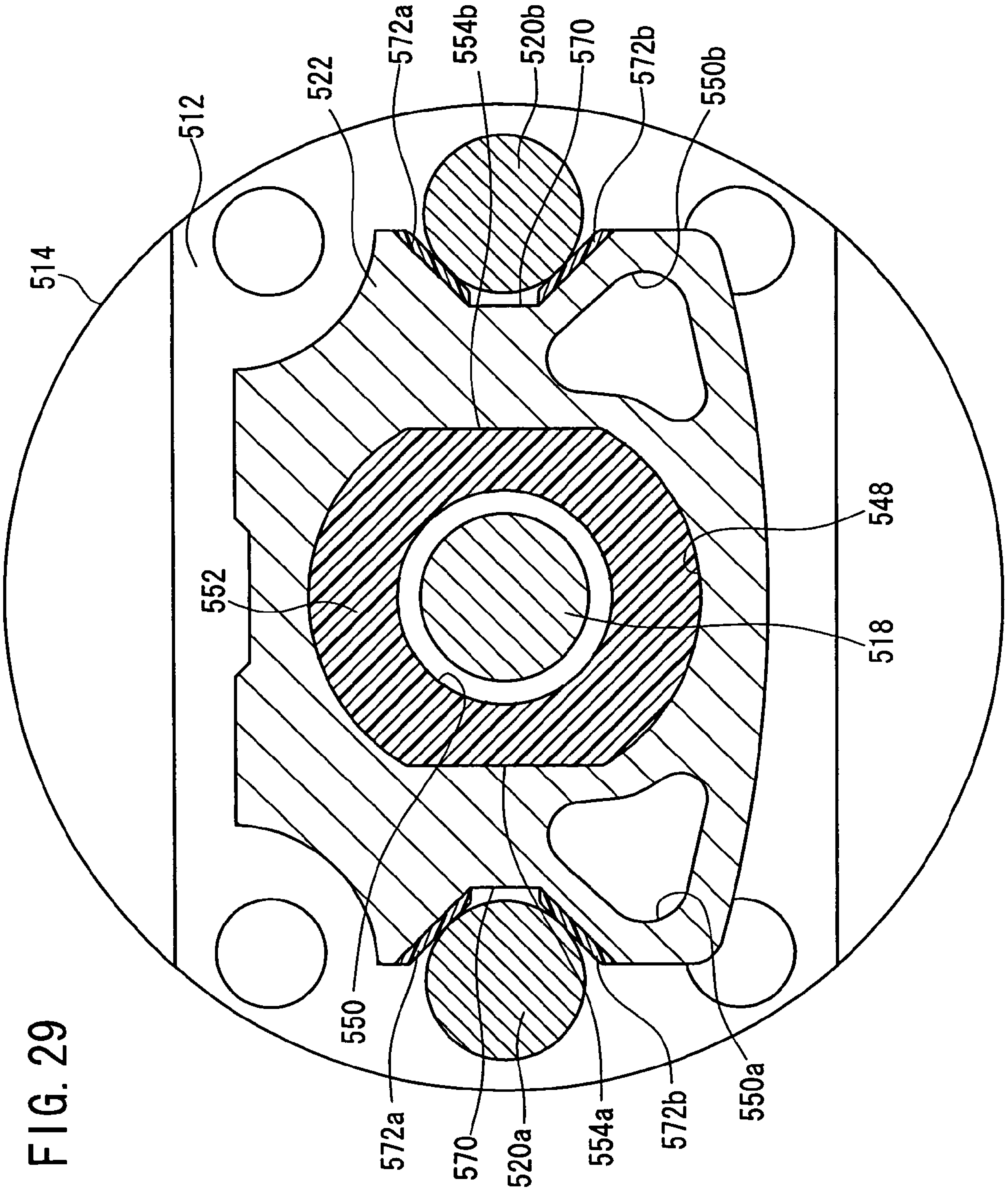
521a
546
524
544
526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522
572a
554b
520b
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572a
570
520a
554a
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550a

FIG. 29

FIG. 30

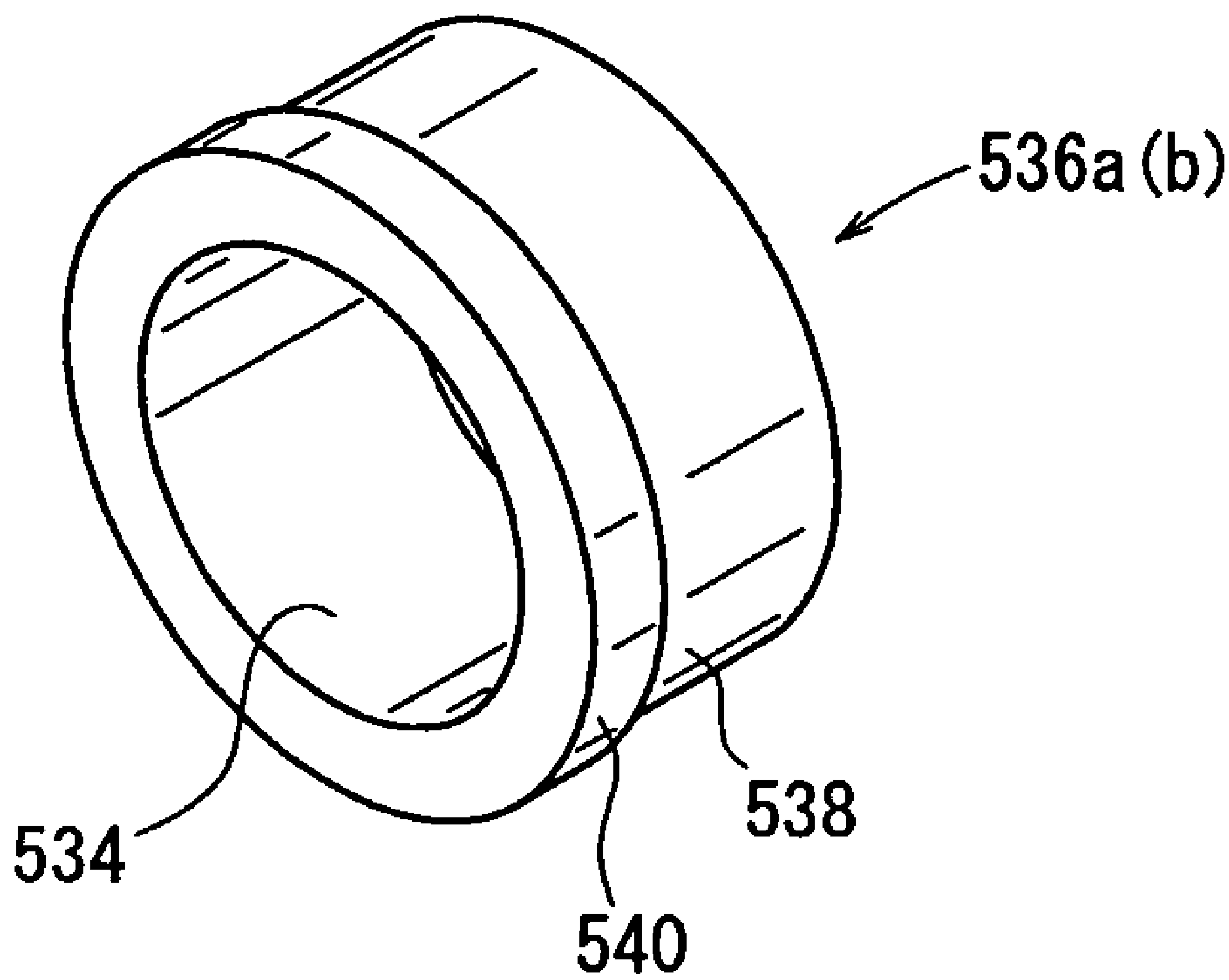


FIG. 31

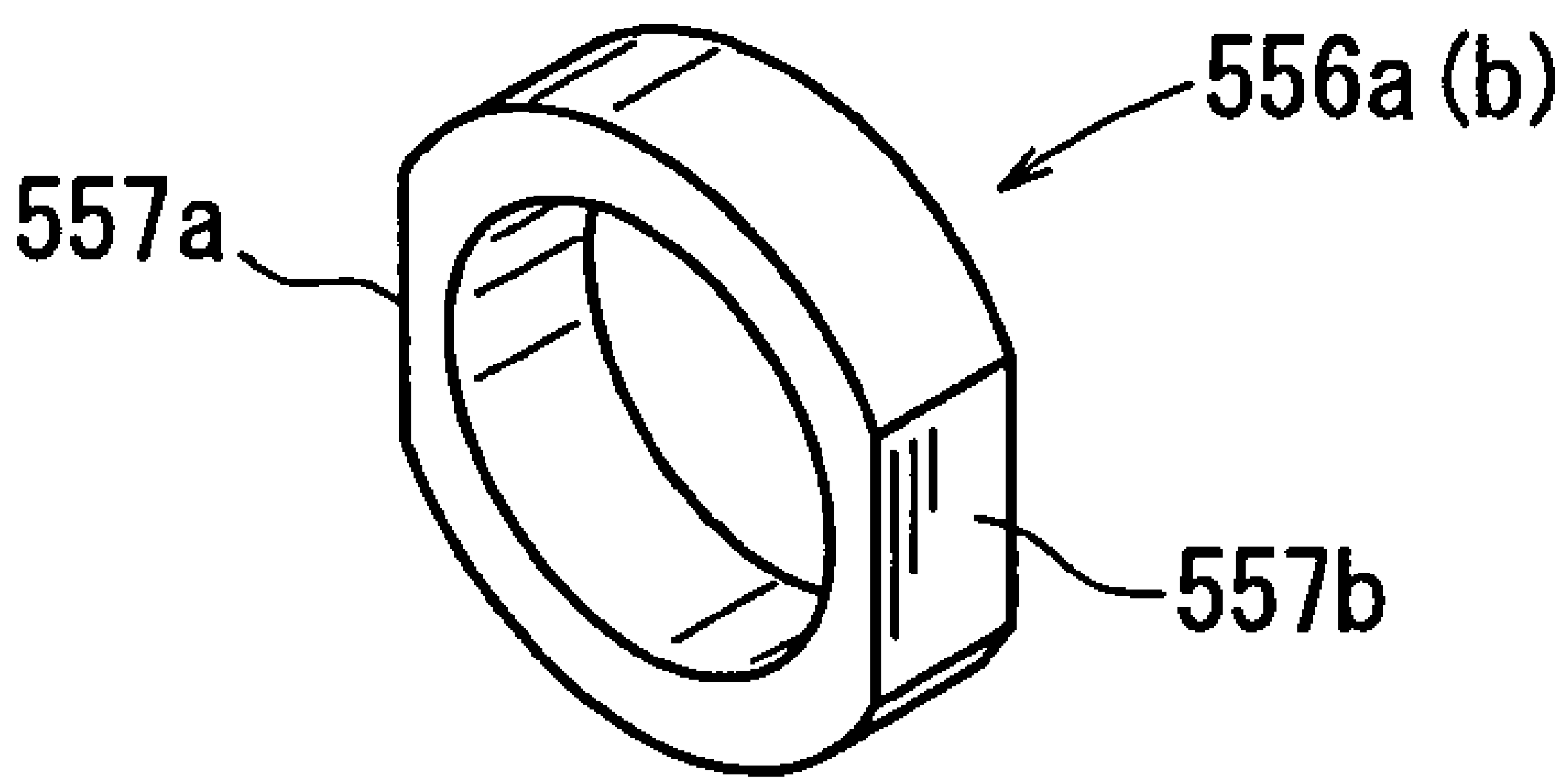
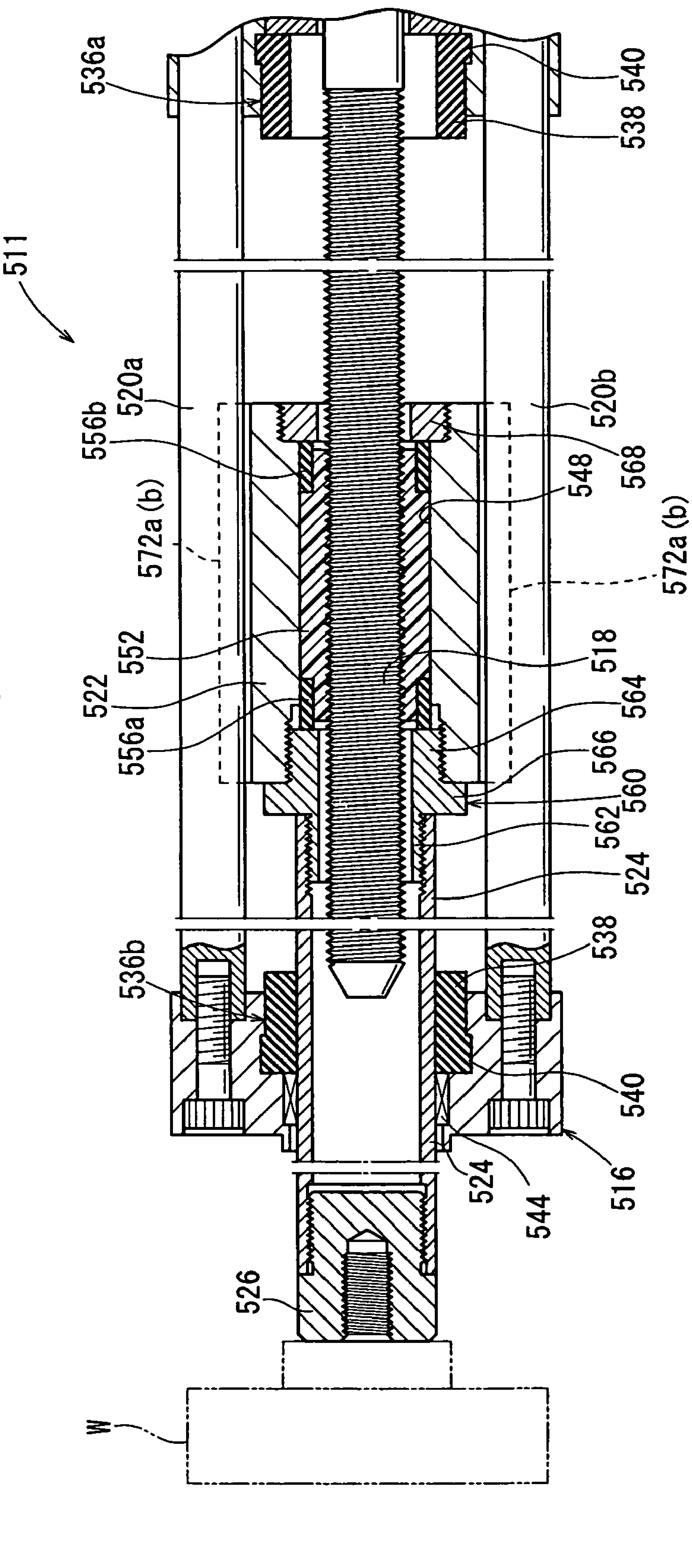


FIG. 32


536a
540
538
511
520a
520b
556b
568
548
572a (b)
572a (b)
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566
560
562
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536b
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516
526
W

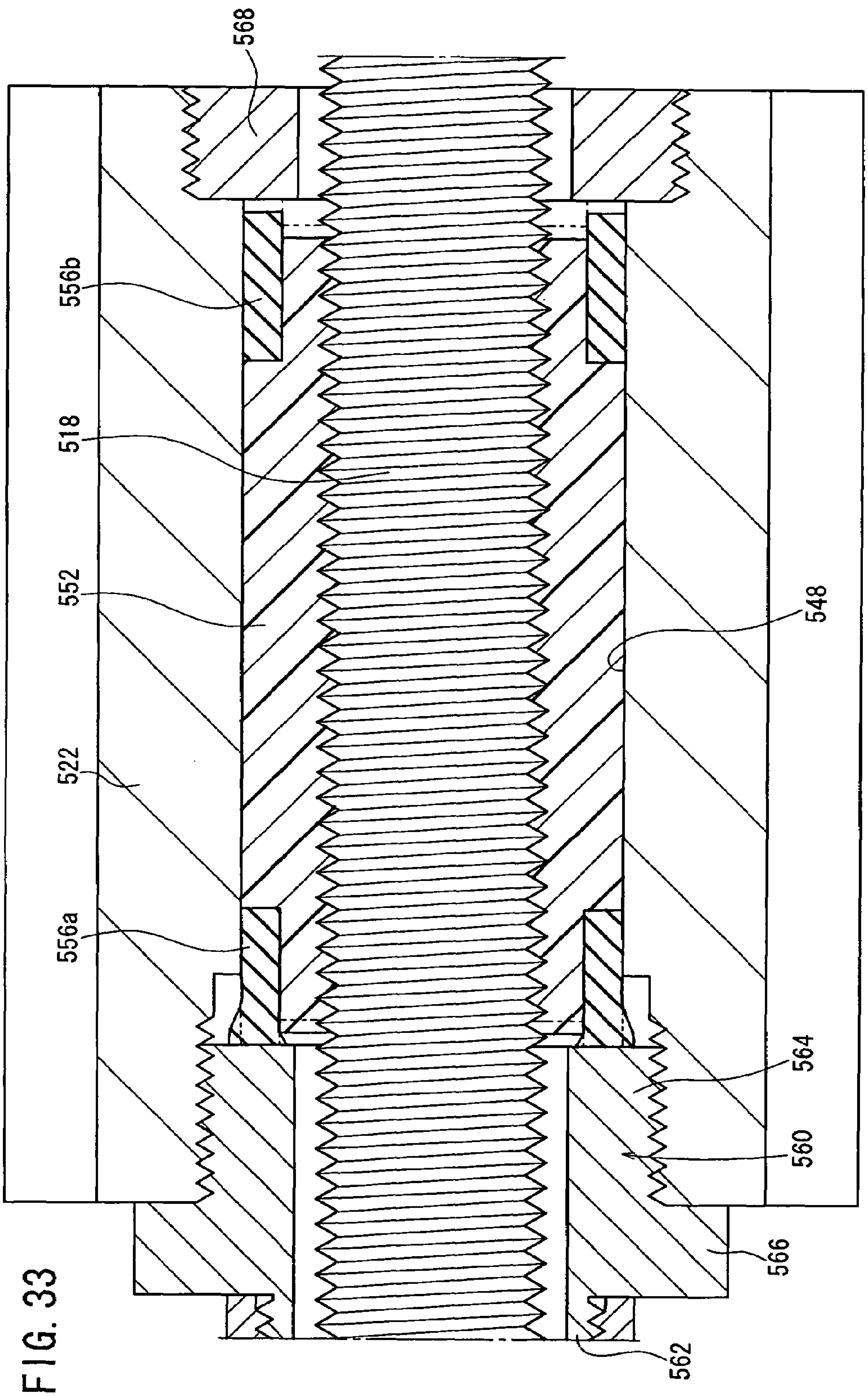
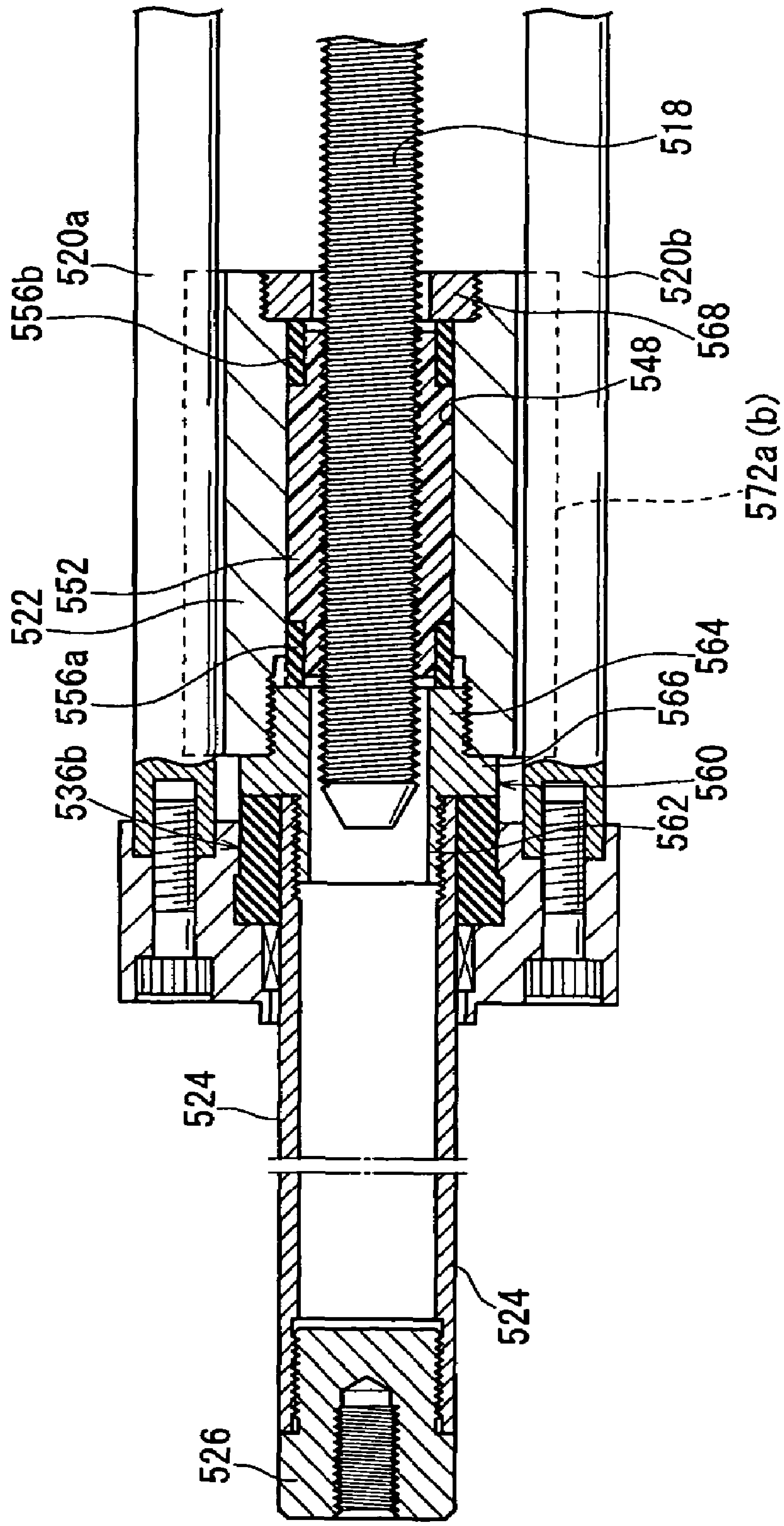


FIG. 33

FIG. 34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556a
564
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536b
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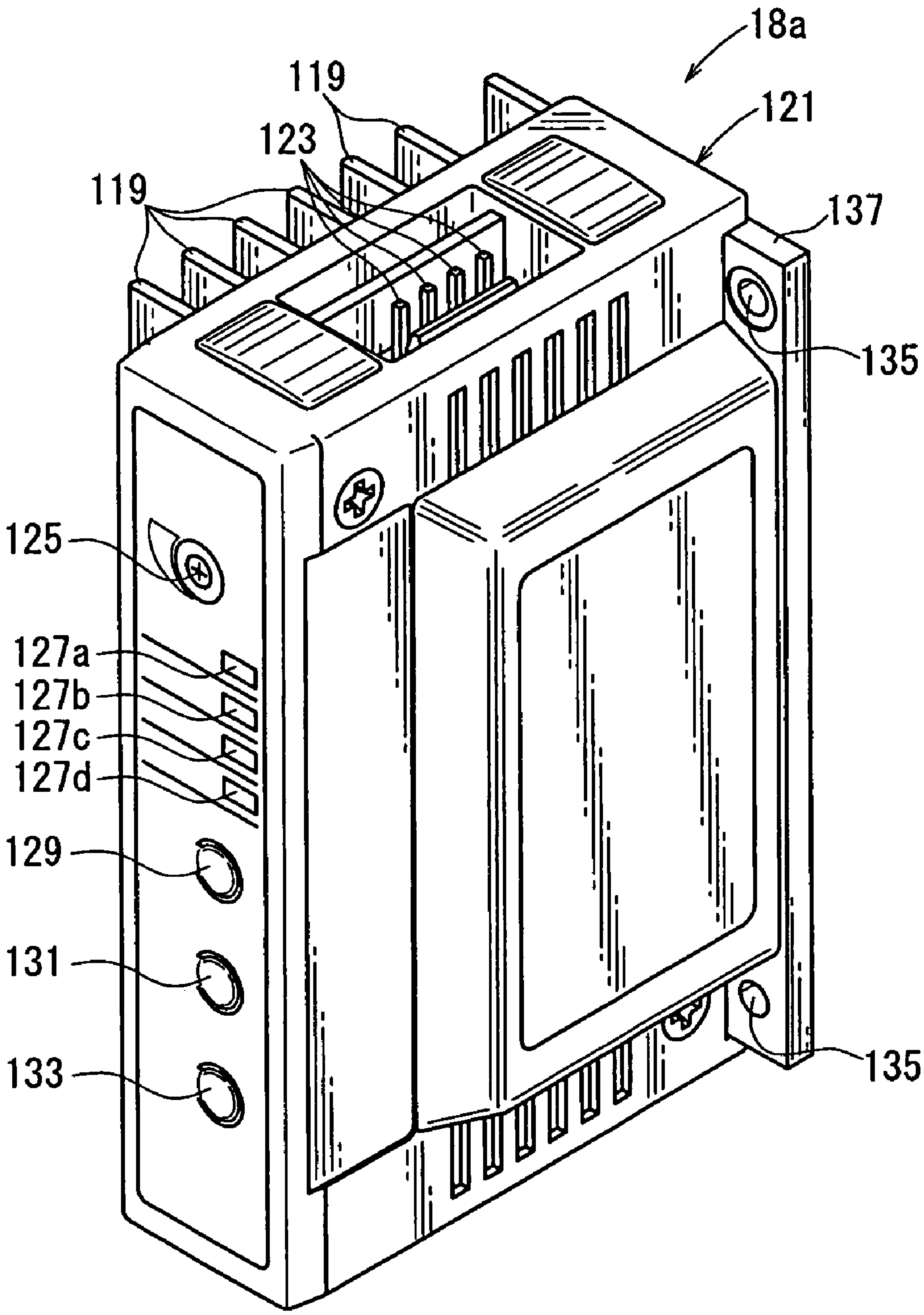
526

FIG. 35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127b
127c
127d
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135
133

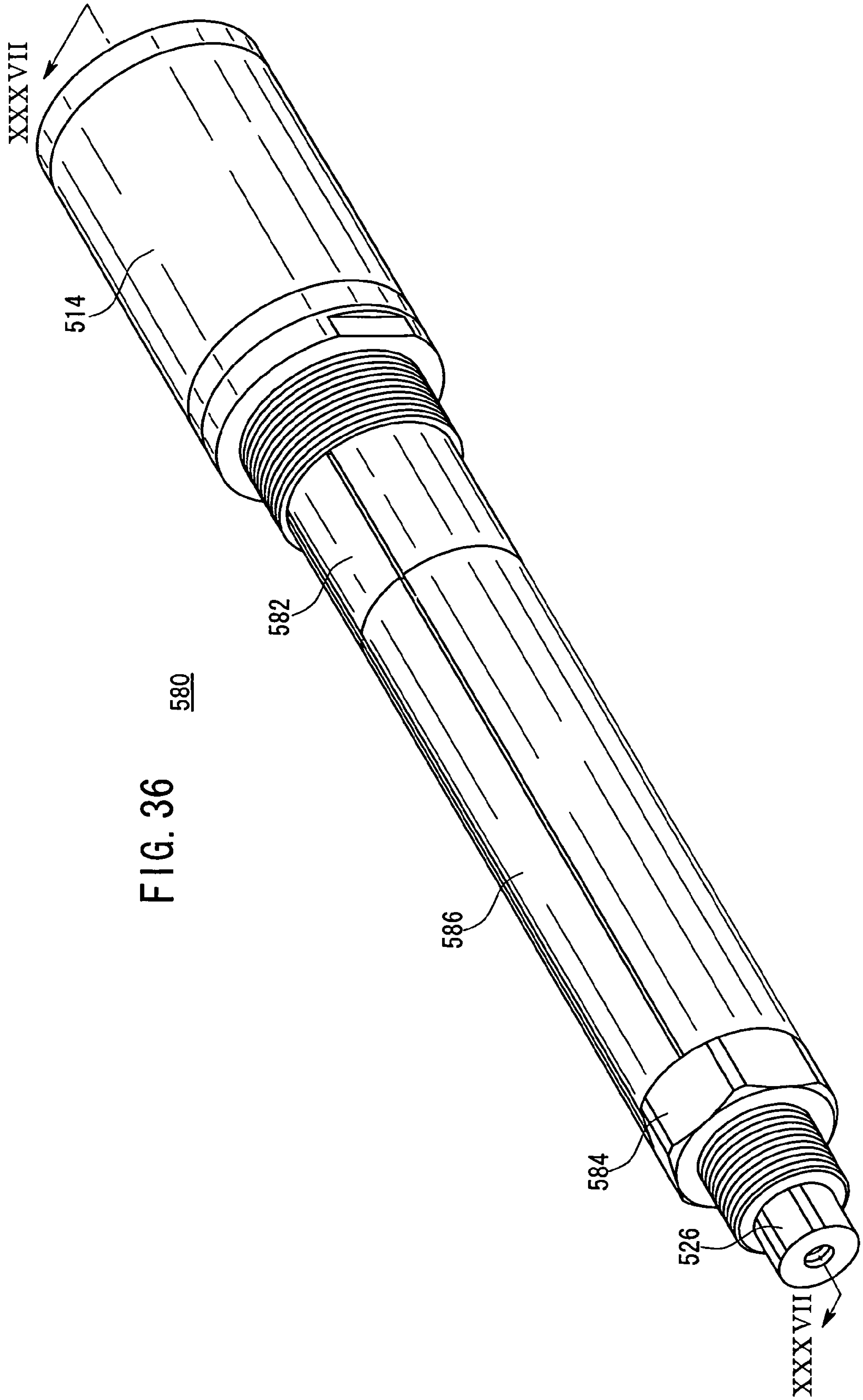
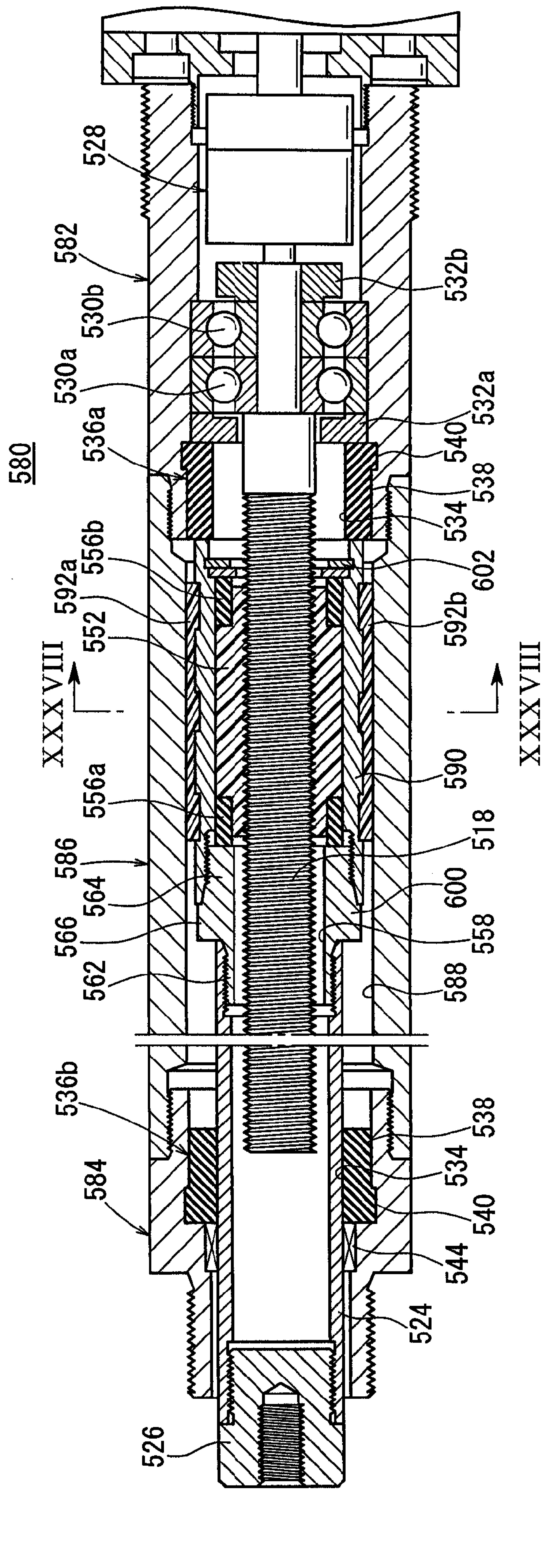


FIG. 36


528
582
530b
530a
536a
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532b
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538
534
602
556b
592a
552
592b
XXXVIII
XXXVIII
590
556a
518
586
564
600
566
558
562
588
536b
538
534
584
540
544
524
526

FIG. 37

FIG. 38

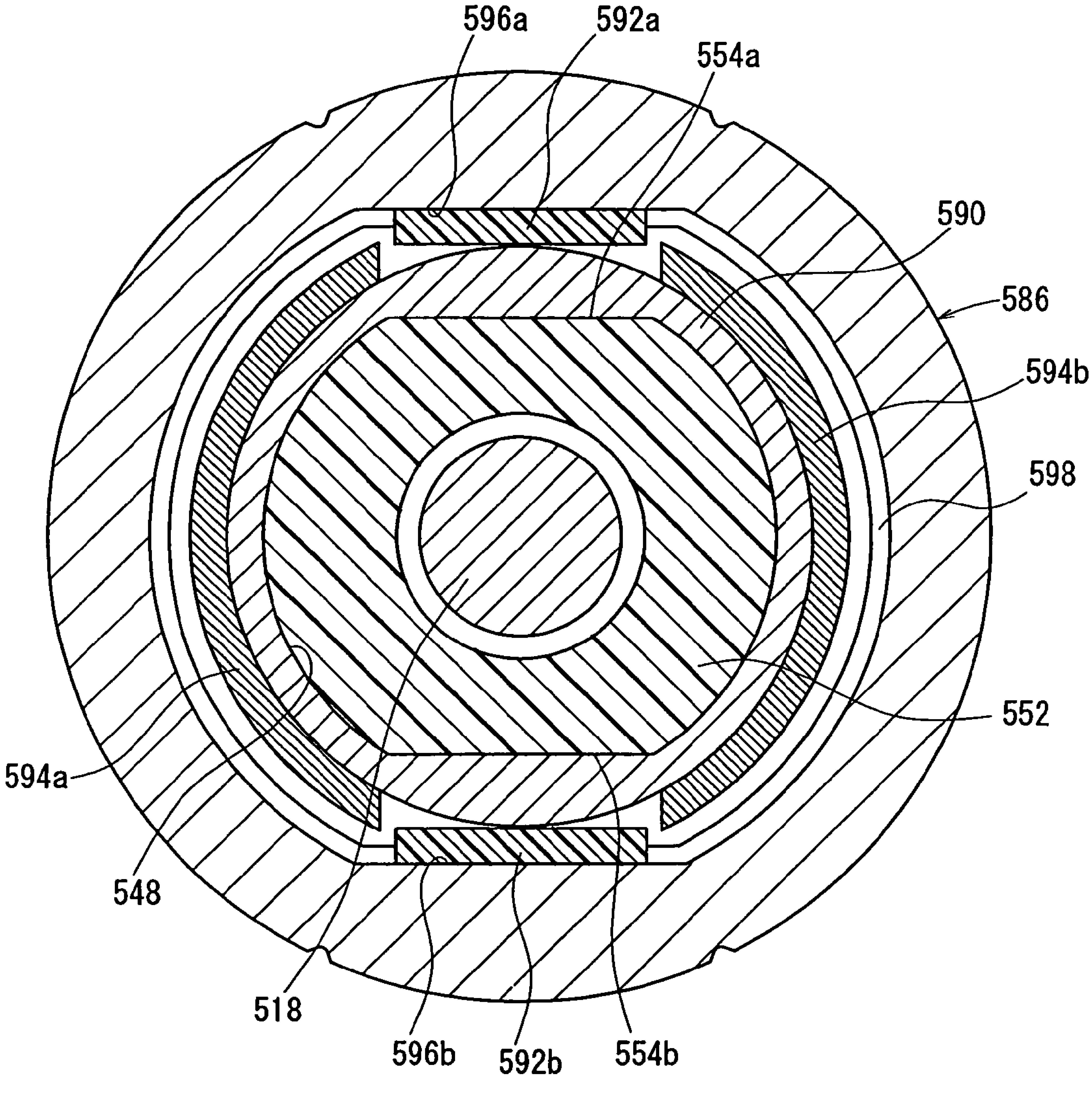

596a
592a
554a
590
586
594b
598
552
594a
548
518
596b
592b
554b

FIG. 39

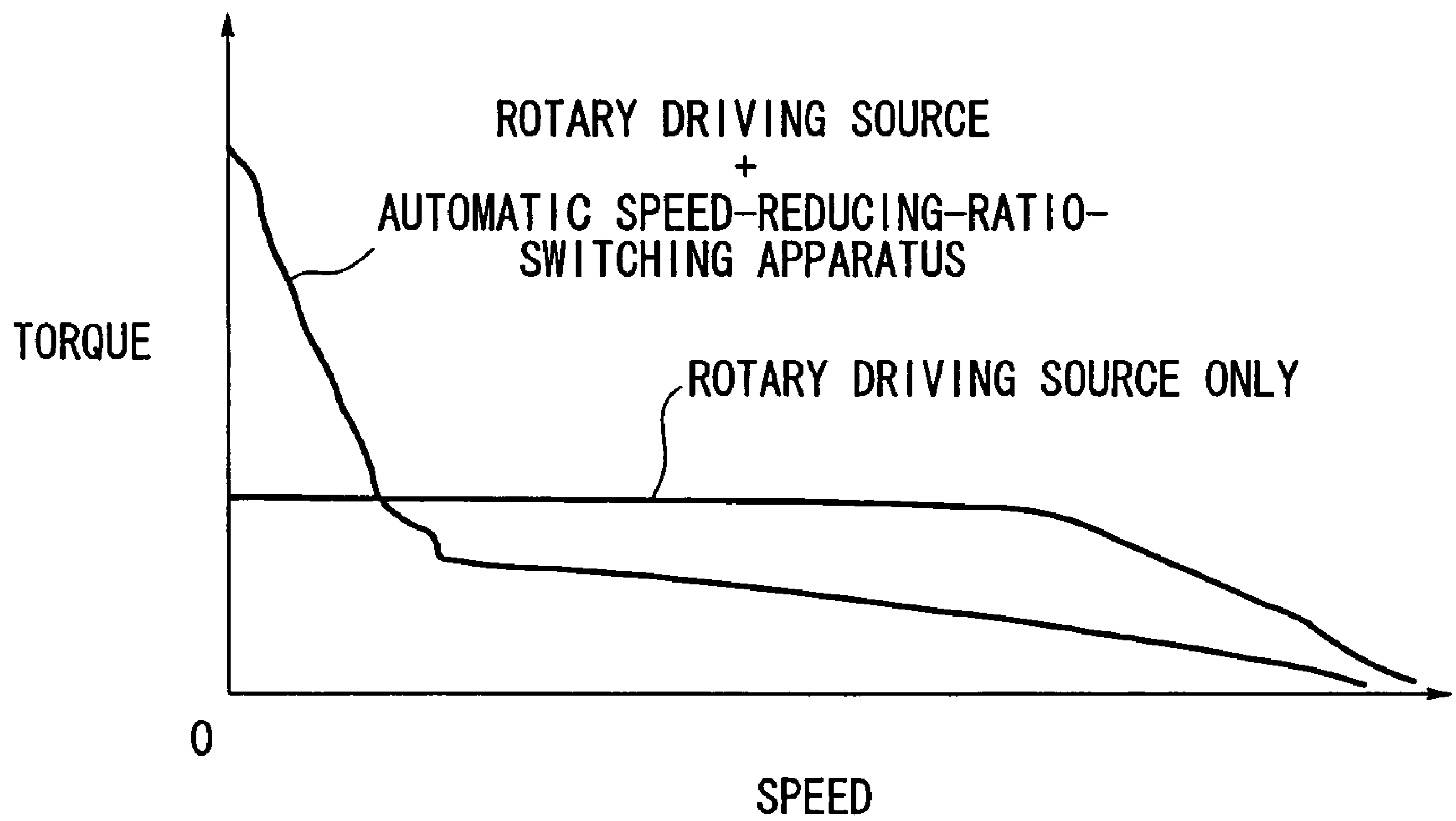

ROTARY DRIVING SOURCE
+
AUTOMATIC SPEED-REDUCING-RATIO-
SWITCHING APPARATUS
TORQUE
ROTARY DRIVING SOURCE ONLY
0
SPEED

FIG. 40

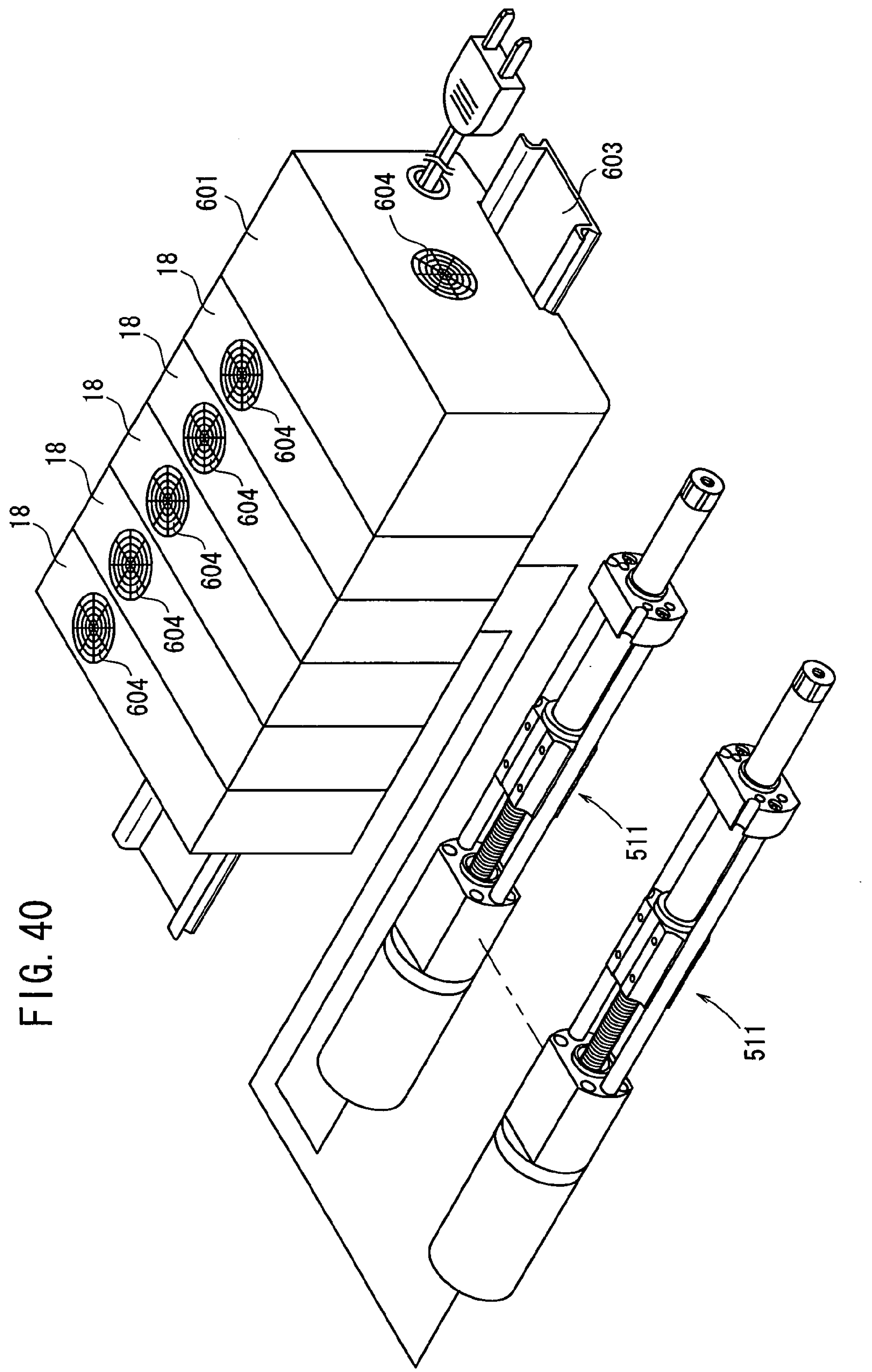


FIG. 41

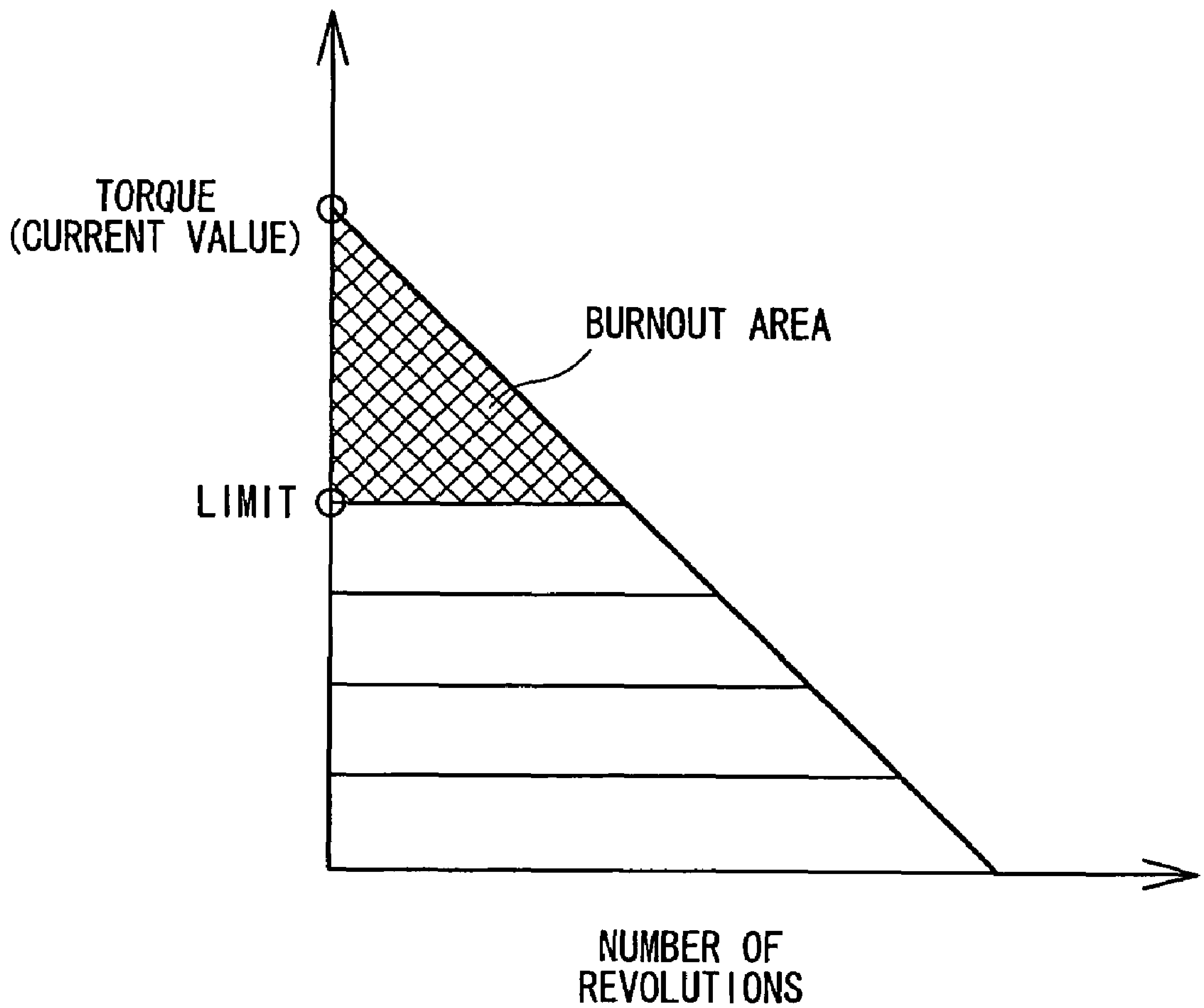
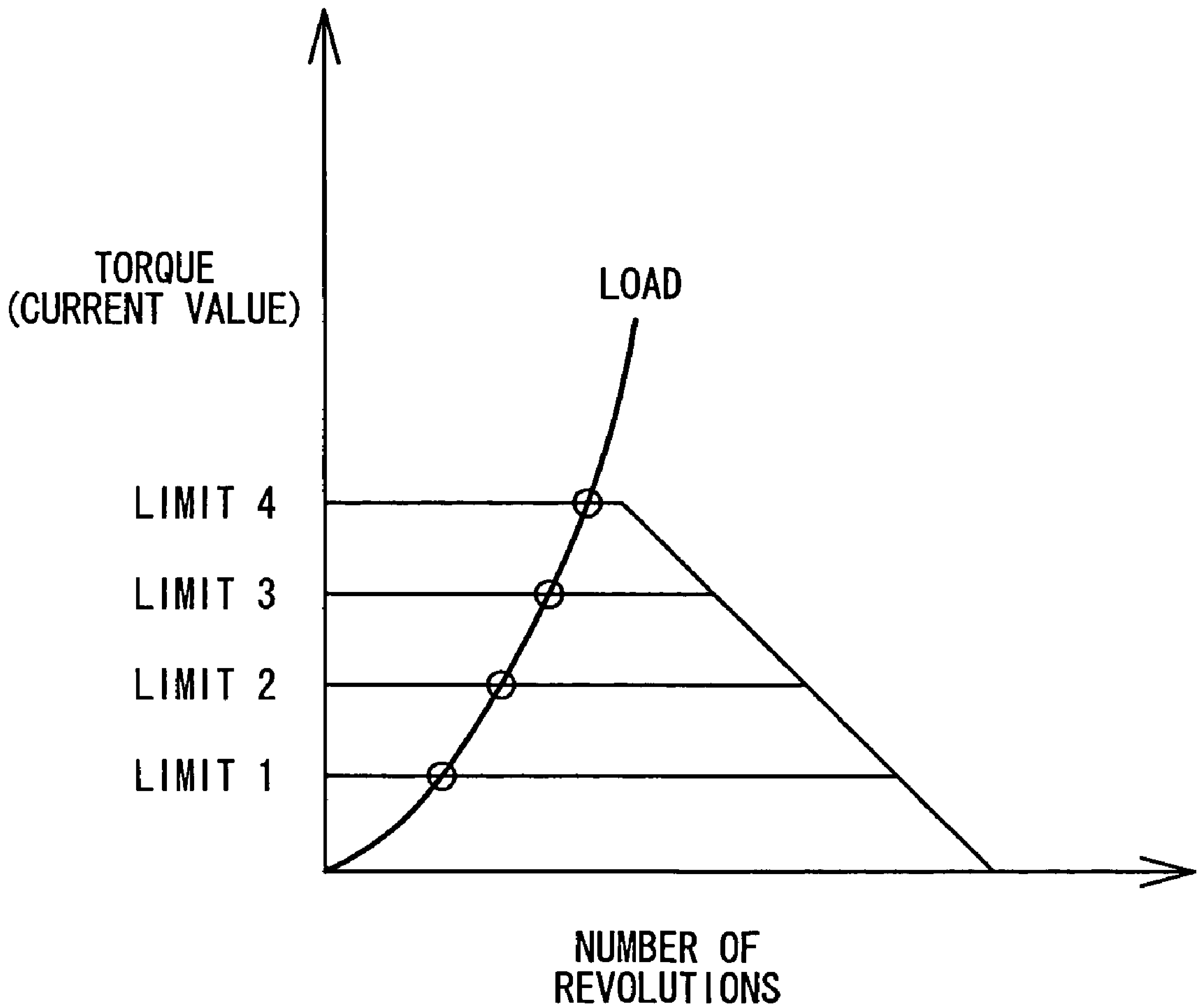

TORQUE
(CURRENT VALUE)
BURNOUT AREA
LIMIT
NUMBER OF
REVOLUTIONS

FIG. 42


TORQUE
(CURRENT VALUE)
LOAD
LIMIT 4
LIMIT 3
LIMIT 2
LIMIT 1
NUMBER OF
REVOLUTIONS

CONTROL SYSTEM FOR ELECTRIC ACTUATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to a control system for an electric actuator, which is capable of appropriately protecting a rotary driving source for driving the electric actuator.

2. Description of the Related Art:

In general, when an installation type industrial robot is used, a base is fixed by bolts or the like. When a tip end of the robot is excessively pressed or smashed by malfunctioning of the interlock or the like, the operation of the robot is stopped by detecting an overcurrent condition. That is, it is principally intended to prevent the robot and the workpiece from being destroyed, by detecting the overcurrent condition of the installation type industrial robot. The positional deviation of the robot itself is not taken into consideration.

In view of the above, Japanese Laid-Open Patent Publication No. 2002-66969 discloses a technical concept which is directed to prevent an automatic or unmanned transport vehicle from floating even when a tip end of a robot arm is excessively pressed to or smashed against surrounding equipment.

That is, Japanese Laid-Open Patent Publication No. 2002-66969 discloses a control apparatus which executes an operation for limiting current flowing to a servo motor for driving a joint of the robot arm if joint torque applied to the joint of the robot arm meets a predetermined limit value, when the tip end of the robot arm is moved based on attitude control and position control of the robot arm.

However, when the technical concept disclosed in the Japanese Laid-Open Patent Publication No. 2002-66969 is applied, for example, to an electric actuator for converting a rotary motion of a motor into a rectilinear motion of a slider or the like, it is necessary to provide a detector such as an encoder and a resolver, and a control circuit in order to control, for example, the position and the operation speed of the slider, in which the production cost becomes expensive.

SUMMARY OF THE INVENTION

A general object of the present invention is to provide a control system for an electric actuator, wherein the control system makes it possible to limit current to be applied to a rotary driving source by using a simple circuit, even when high load is applied to the rotary driving source which is provided in order to drive the electric actuator.

The above and other objects, features, and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which a preferred embodiment of the present invention is shown by way of illustrative example.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view illustrating a control system according to an embodiment of the present invention in which a driver for an electric actuator is incorporated;

FIG. **2** is a schematic block diagram illustrating an arrangement of the driver for the electric actuator shown in FIG. **1**;

FIG. **3** is a block diagram illustrating an arrangement of a current amplifier/limiter shown in FIG. **2**;

FIG. **4** is a characteristics chart illustrating the relationship between a displacement amount of a slider of the electric actuator and a current supplied to a rotary driving source;

FIG. **5** is a block diagram illustrating an arrangement of a relay circuit concerning Comparative Example 1;

FIG. **6** is a block diagram illustrating an arrangement of a servo circuit concerning Comparative Example 2;

FIG. **7** is a side view illustrating a modified embodiment of an electric actuator;

FIG. **8** is a side view illustrating a frame of an electric actuator;

FIG. **9** is a partially cross-sectional plan view illustrating a modified embodiment of an electric actuator;

FIG. **10** is a perspective view illustrating a modified embodiment of an electric actuator to which a cover is attached;

FIG. **11** is a perspective view illustrating a modified embodiment of an electric actuator equipped with a sensor by a holder;

FIG. **12** is a perspective view illustrating a modified embodiment in which an electric actuator and an actuator utilizing compressed air are used in combination;

FIG. **13** is a perspective view illustrating a modified embodiment of an electric actuator to which a vacuum port is connected;

FIG. **14** is a partial magnified longitudinal sectional view illustrating a dust seal provided for the electric actuator shown in FIG. **13**;

FIG. **15** is a partially cross-sectional plan view illustrating a modified embodiment of an electric actuator having a resin needle shaft between a frame and a slider;

FIG. **16** is a front view illustrating a modified embodiment of an electric actuator;

FIG. **17** is a perspective view illustrating a state in which electric actuators are assembled along with the three axes of X, Y, and Z;

FIG. **18** is a longitudinal sectional view, which is taken in the axial direction, illustrating an apparatus for automatically switching speed reducing ratio proposed by SMC KABUSHIKI KAISHA;

FIGS. **19**A to **19**C are sectional views illustrating connections between input shafts and output shafts in the apparatus for automatically switching speed reducing ratio, respectively;

FIGS. **20**A to **20**D are sectional views illustrating situations in which various mechanisms are provided between input shafts and output shafts in the apparatus for automatically switching speed reducing ratio, respectively;

FIG. **21** is a partial longitudinal sectional view illustrating a state in which a slider is displaced by means of a belt;

FIG. **22** is, with partial cutout, a side view illustrating an electric clamp apparatus;

FIG. **23** is a vertical sectional view, which is taken in the axial direction, illustrating the electric clamp apparatus;

FIG. **24** is, with partial cutout, a side view illustrating a state in which a hydraulic cylinder is juxtaposed;

FIG. **25** is a longitudinal sectional view, which is taken in the axial direction, illustrating a modified embodiment of the apparatus for automatically switching speed reducing ratio;

FIG. **26** is a perspective view illustrating a control system into which a driver according to a modified embodiment is incorporated;

FIG. **27** is a perspective view illustrating an electric actuator for constructing the system;

FIG. **28** is a partial longitudinal sectional view taken in the axial direction of the electric actuator shown in FIG. **27**;

FIG. **29** is a magnified vertical sectional view taken along the line XXIX-XXIX shown in FIG. **27**;

FIG. **30** is a perspective view illustrating an end damper;

FIG. **31** is a perspective view illustrating a piston damper;

FIG. **32** is a partial longitudinal sectional view illustrating a state in which a piston rod abuts against a workpiece at an intermediate position;

FIG. **33** is a partial magnified longitudinal sectional view illustrating a state in which impact is absorbed by the piston damper in the state shown in FIG. **32**;

FIG. **34** is a partial magnified longitudinal sectional view illustrating a state in which impact is absorbed by the piston damper and the end damper at the frontward movement end of the piston rod;

FIG. **35** is a perspective view illustrating a driver for constructing the system;

FIG. **36** is a perspective view illustrating another electric actuator to be incorporated into the system;

FIG. **37** is a partial longitudinal sectional view taken along the line XXXVII-XXXVII shown in FIG. **36**;

FIG. **38** is a partial magnified longitudinal sectional view taken along the line XXXVIII-XXXVIII shown in FIG. **37**;

FIG. **39** is a characteristics chart illustrating the relationship between torque and speed obtained when a rotary driving source is used alone or with a speed reducer;

FIG. **40** is a perspective view in which a plurality of direction control drivers are assembled into a manifold;

FIG. **41** is a characteristics chart illustrating motor driver characteristics; and

FIG. **42** is a characteristics chart illustrating the load-speed control characteristics.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIG. **1**, reference numeral **10** indicates a control system according to an embodiment of the present invention into which a driver for an electric actuator (hereinafter referred to as the "driver") is incorporated.

The control system **10** comprises an electric actuator **16** which includes a slider **14** that makes linear reciprocating motion under driving action of a rotary driving source **12**, a driver **18** which energizes and deenergizes the rotary driving source **12** equipped for the electric actuator **16**, and a controller **20** which outputs a direction instruction signal to the driver **18**.

The controller **20** and the driver **18** are provided connectably via a rail member **22** which is engageable with recesses formed on each back surface of the casings of the controller **20** and the driver **18**.

The rotary driving source **12** may be constructed by a motor, such as a brush DC motor, a brushless DC motor, an AC servo motor, an induction motor, and a stepping motor, to be driven and rotated. A linear motor such as a solenoid may be used in place of the rotary driving source **12**.

The electric actuator **16** includes an actuator body **24**, the rotary driving source **12** which is connected to one end of the actuator body **24** by screw members, a pair of guide shafts **28***a*, **28***b* which extend in parallel between the actuator body **24** and an end block **26**, and a ball screw shaft **30** which is connected to a drive shaft of the rotary driving source **12** by an unillustrated coupling member.

The electric actuator **16** further includes the slider **14** which has an unillustrated ball screw nut screwed to the ball screw shaft **30** and which makes linear reciprocating motion with guidance of the pair of guide shafts **28***a*, **28***b*, and a rod **32** which is connected to the slider **14** and which has its part projecting toward the outside from the hole of the end block **26** and moving back and forth integrally with the slider **14**. The slider **14** and the rod **32** function as the movable member.

Next, FIG. **2** shows a schematic block diagram illustrating an arrangement of the driver **18**.

The driver **18** includes a direction-switching means **34** which switches the rotation direction of the rotary driving source **12** into a forward or backward direction by switching the polarity of the voltage in accordance with the direction instruction signal derived from the controller **20**, and a current amplifier/limiter **36** which converts a voltage outputted from the direction-switching means **34** into a corresponding current and which limits the current with reference to the preset reference current I_{MAX} (threshold value).

The driver **18** further includes a current sensor (current-detecting means) **38** which is provided on the downstream side of the current amplifier/limiter **36** and which detects the current to be supplied to the rotary driving source **12**, and a current loop **40** which feeds back a detection signal from the current sensor **38** to the upstream side of the current amplifier/limiter **36**.

As shown in FIG. **3**, the current amplifier/limiter **36** is provided with a comparing means **44** which compares the preset reference current I_{MAX} stored in a storage means **42** with the detection signal of the current value supplied from the current sensor **38** via a detection line **41**, and a current limit means **46** which limits the current to be supplied to the rotary driving source **12** so that the current does not exceed the reference current I_{MAX}, for example, when a high load is applied to the rotary driving source **12** and the current to be supplied to the rotary driving source **12** exceeds the reference current I_{MAX}.

The driver **18** has an unillustrated circuit board. For example, the current sensor **38** is preferably composed of a small resistor arranged on the circuit board. The driver **18** is connected to a power source **86** via a connector.

The control system **10** according to the embodiment of the present invention, into which the driver **18** is incorporated, is basically constructed as described above. Next, its operation, function, and effect will be explained.

At first, the direction instruction signal from the controller **20** is introduced into the driver **18**. The driver **18** switches the rotation direction of the rotary driving source **12** into any one of the forward and backward directions by switching the polarity of the voltage based on the direction instruction signal. The voltage, which corresponds to the current supplied from the direction-switching means **34** to the rotary driving source **12**, is inputted into the current amplifier/limiter **36**.

The current amplifier/limiter **36** converts a voltage outputted from the direction-switching means **34** into a current which is supplied to the rotary driving source **12**. Accordingly, the rotary driving source **12** is driven and rotated in the predetermined direction.

The rotary motion of the rotary driving source **12** is transmitted to the ball screw shaft **30** connected to the drive shaft of the rotary driving source **12**. The rotary motion is converted into the rectilinear motion through screw engagement between the ball screw shaft **30** and the unillustrated ball screw nut. The rectilinear motion is transmitted to the slider **14**. Therefore, for example, the rod **32** extends outside integrally with the slider **14** to press an unillustrated workpiece to a predetermined position.

When the workpiece is pressed at the predetermined position by the rod **32**, and high load is applied to the rotary driving source **12**, after the slider **14** reaches the stroke end, the rotation of the drive shaft of the rotary driving source **12** is stopped and restricted. In this situation, torque, which is outputted from the drive shaft of the rotary driving source **12**, is proportional to the current applied to the rotary driving source **12**. Therefore, when the rotary motion is restricted, the current (overcurrent), which exceeds the predetermined value, may be undesirably applied to the rotary driving source **12**, causing burnout of the rotary driving source **12**.

Accordingly, in the embodiment of the present invention, the detection signal from the current sensor **38** for detecting the current to be supplied to the rotary driving source **12** is introduced into the current amplifier/limiter **36** via the detection line **41**. The current amplifier/limiter **36** compares the detection signal from the current sensor **38** with the preset reference current I_{MAX} stored in the storage means **42** by the comparing means **44**. Further, the current to be supplied to the rotary driving source **12**, is limited not to exceed the reference current I_{MAX} by the current limit means **46** (see FIG. **4**).

As described above, in the embodiment of the present invention, the value of current to be supplied to the rotary driving source **12** is checked by the current sensor **38**, and then the current amplifier/limiter **36** limits the current applied to the rotary driving source **12** to be equal to or lower than the reference current I_{MAX}. As a result, even when the high load is applied to the rotary driving source **12**, and the drive shaft of the rotary driving source **12** in an ON state is stopped and restricted, the rotary driving source **12** can be prevented from being burnt out due to overcurrent, because the current supplied to the rotary driving source **12** is limited not to exceed the preset reference current I_{MAX}. The torque, of course, can be controlled by limiting the current applied to the rotary driving source **12**.

In the embodiment of the present invention, it is unnecessary to provide a detector such as an encoder and a resolver, and a control circuit to control operation speed and position of the slider **14**. The rotary driving source **12** can be prevented from being burnt out by using a simple circuit such as the current amplifier/limiter **36**, making it possible to reduce production cost.

In this arrangement, it is preferable that the driver **18** is applied to the driving apparatus (electric actuator) in which only the pressing action by the rod **32** and the rotation direction of the rotary driving source **12** are controlled.

Though not restrictive, the present invention has been explained based on the embodiment where a workpiece is pressed by the rod **32** of the electric actuator **16**, and applicable, for example, to transporting, caulking, pushing or supporting the workpiece by the rod **32** of the electric actuator **16**, to grip the workpiece by an unillustrated electric chuck, or to clamp the workpiece by an electric clamp as described later on.

FIGS. **7** to **17** show modified embodiments of the electric actuator **16**. In the modified embodiments, the same components as those of the embodiment described above are designated by the same reference numerals, and detailed explanation thereof will be omitted.

In the modified embodiment shown in FIG. **7**, the guide shafts **28***a*, **28***b* are surrounded by a frame **100** made of light alloy such as aluminum, in the electric actuator **16**, to guide the slider **14** more accurately.

In the modified embodiment shown in FIG. **8**, the electric actuator **16** is provided with a frame **104** formed with a space **102** for accommodating the rotary driving source **12** and surrounding the guide shafts **28***a*, **28***b*. The frame **104** can be thin-walled to have a light weight with enhanced rigidity.

In the modified embodiment shown in FIG. **9**, the electric actuator **16** is provided with guide units **106***a*, **106***b* for guiding the guide shafts **28***a*, **28***b*, and tip ends of the guide shafts **28***a*, **28***b* are connected to one another via a plate **108**. Further, bushes **110** are provided in the guide units **106***a*, **106***b*.

In the modified embodiment shown in FIG. **10**, a cover **112** is attached to the electric actuator **16** whose rigidity is enhanced by the frame **104** as described above. A pair of sensors **114**, **114** are provided in a groove of the cover **112** in order to detect the position of the slider **14**. Those usable as the sensor **114** include various sensors such as magnetic sensors, proximity sensors, and photo-micro sensors.

The modified embodiment shown in FIG. **11** relates to the modified embodiment shown in FIG. **9**, in which a holder **120** is attached to a cover **116** having a circular cross section by a band **118**. The sensor **114** is retained by the holder **120**.

The modified embodiment shown in FIG. **12** relates to such an arrangement that an actuator **122** utilizing compressed air is further provided with the electric actuator **16** using the rotary driving source **12**. Air pipes **124***a*, **124***b* are connected to the actuator **122**. Silencers **126***a*, **126***b* are provided closely to the pipes **124***a*, **124***b* in order to make soundproof when the compressed air is discharged.

The modified embodiment shown in FIG. **13** is constructed as follows. That is, a vacuum port **130** is connected to the electric actuator **16** to obtain a vacuum state in the space between the rod **32** and a cover **132** surrounding the rod **32** to remove dust which may be generated during the sliding movement of the rod **32**. A dust seal **134**, which contacts and presses the circumferential wall surface of the rod **32**, may be provided at the tip end of the cover **132** as well (see FIG. **14**).

The modified embodiment shown in FIGS. **15** and **16** is constructed as follows. That is, a plurality of needle shafts **140** made of resin, preferably three on one side and six in total on both sides, extend in the axial direction between the frame **100** and the slider **14** in the electric actuator **16** in place of the guide shafts **28***a*, **28***b*. Such an electric actuator **16** can be produced more inexpensively.

In each of the modified embodiments shown in FIGS. **7** to **16** described above, the rod **32** moves forward and backward two-dimensionally. However, a plurality of the electric actuators **16** can be combined three-dimensionally to perform the three-dimensional action. Such an arrangement is shown in FIG. **17**.

In the modified embodiment shown in FIG. **17**, the electric actuators **16** are attached along the X axis, the Y axis, and the Z axis, respectively, to make the rod **32** of the electric actuator **16** for the Z axis move three-dimensionally from a big point of view.

That is, when a high load is applied to the rotary driving source **12** as a result of, for example, the workpiece-transporting operation, the workpiece-gripping operation, or the clamping operation as described above, and the rotation of the drive shaft of the rotary driving source **12** is stopped and restricted, the current to be supplied to the rotary driving source **12** is limited not to exceed the reference current I_{MAX}.

Next, an explanation will be made about Comparative Example 1 and Comparative Example 2 to be compared with the embodiments of the present invention. The same components as those of the embodiments of the present invention are designated by the same reference numerals, and detailed explanation thereof will be omitted.

FIG. **5** shows a relay circuit **50** concerning Comparative Example 1. In this arrangement, when a plurality of the relay circuits **50** are combined, it is possible to switch the direction of rotation of the rotary driving source **12**. However, when the drive shaft of the rotary driving source **12** is stopped and restricted, current exceeding capacity of the rotary driving source **12** may be supplied and cause burnout thereof.

FIG. **6** shows a servo circuit **60** concerning Comparative Example 2. The servo circuit **60** has a detector such as a resolver and an encoder **62**, comprising a control circuit for feedback-controlling speed by a speed loop **64** and a speed amplifier/limiter **66**, and a control circuit for positioning by a position loop **68** and a position amplifier/limiter **70**. Therefore, the servo circuit **60** concerning Comparative Example 2 requires highly accurate control circuits for controlling, for example, the position and the speed. Therefore, the servo circuit **60** is expensive, and the production cost becomes high.

On the contrary, the embodiment of the present invention makes it possible to incorporate part of functions of the relay circuit **50** concerning Comparative Example 1 and the servo circuit **60** concerning Comparative Example 2 at a low cost. Further, in the embodiment of the present invention, the electric actuator **16** can be operated in accordance with the ON/OFF control in the same manner as the solenoid-operated valve, and thus the electric actuator **16** can be used as a direction-controlling apparatus optimally, for example, for pressing, transporting, etc. Further, in the embodiment of the present invention, it is unnecessary to provide a detector such as an encoder additionally provided outside the rotary driving source **12**. Therefore, it is possible to reduce size and weight.

In the embodiment described above, the relationship between the rotary driving source **12** and the ball screw shaft **30** is not explained in detail. Of course, the both may be directly connected to one another. However, a mechanism for switching speed reducing ratio may also be interposed therebetween. As for such a speed reducing ratio-switching mechanism, SMC KABUSHIKI KAISHA has proposed "an apparatus for automatically switching speed reducing ratio" as Japanese Patent Application No. 2004-170263. With reference thereto in this application, as shown in FIG. **18**, helical gears are used as a sun gear **216**, planet gears **218**, and an internal gear **220**. Accordingly, when a load, which exceeds a predetermined torque, is applied to the internal gear **220**, the internal gear **220** is moved in the direction toward the input shaft or the direction toward the output shaft, while being rotated in the direction different from that of the sun gear **216**, and thus the speed reducing ratio is automatically switched.

Various embodiments are also conceived in relation to the direct connection between the rotary driving source **12** and the ball screw shaft **30** as described above. In FIG. **19**A, the output shaft, i.e., the input shaft of the ball screw shaft **30** is directly connected to the input shaft, i.e., the output shaft of the rotary driving source **12**. In FIG. **19**B, a viscous coupling **230** is interposed between the input shaft and the output shaft. In FIG. **19**C, a powder clutch **240** is interposed between the input shaft and the output shaft.

As shown in FIG. **20**A, even in an arrangement in which the viscous coupling **230** is interposed, fluid resistance can be increased/decreased by screwing an adjusting screw **250** to press one disk disposed on the side of the output shaft in order to adjust the rotational force of the rotary driving source **12**.

In an arrangement shown in FIG. **20**B, a magnet **260** is provided for a rotor **261** between the input shaft and the output shaft. A plate member **264** made of aluminum or copper is attached inside a casing **262**. The plate member **264** is moved back and forth by an adjusting screw **266** to make rotational resistance variable by changing magnetic fluxes of the magnet **260**. In an arrangement shown in FIG. **20**C, a coil **267** is attached around a rotor **261**. A resistance value of a resistor **268** is changed with respect to the coil **267** in order to control the rotation of the rotor **261**. As shown in FIG. **20**D, a rotor **261** may be simply tightened by a brake **270** to control ON/OFF of the rotation of the rotor **261**.

In the embodiment described above, the rotary driving source **12** and the slider **14** are connected to one another by the ball screw shaft **30** to transmit the rotational force of the rotary driving source **12**. However, there is no limitation to the ball screw shaft **30** as described above. For example, as described in Japanese Laid-Open Patent Publication No. 2005-106284, the slider **14** may be displaced by a belt **300** (see FIG. **21**).

The present invention is also usable for structures in which a rotary driving source **12** and a ball screw shaft **30** are juxtaposed as in an electric clamp apparatus as shown in FIGS. **22** and **23** (Japanese Laid-Open Patent Publication Nos. 2001-105332 and 2002-219625), or a hydraulic cylinder **302** is juxtaposed (Japanese Laid-Open Patent Publication No. 2005-54862, see FIG. **24**).

Additionally, as shown in FIG. **25**, the present invention is also applicable in the following structure. That is, magnets **400**, **402** are provided in each side of a stator and a rotator between the input shaft and the output shaft. A ring gear **404** is moved relatively with respect to a planet gear **406**. The ring gear **404** is forcibly moved to and retained at the neutral position.

Next, FIG. **26** shows a control system **10***a* into which a driver **18***a* according to a modified embodiment is incorporated. The same components as those of the control system **10** shown in FIG. **1** are designated by the same reference numerals, and detailed explanation thereof will be omitted.

The control system **10***a* comprises an electric actuator **511** in which a piston **522** and a piston rod **524** make linear reciprocating motion under the driving action of a rotary driving source **514**, the driver **18***a* which energizes and deenergizes the rotary driving source **514** equipped for the electric actuator **511**, a controller **20** which derives the direction instruction signal to the driver **18***a*, and a power source **523** which is connected to the driver **18***a* via a connector.

As shown in FIG. **27**, the electric actuator **511** includes a housing **512** which is composed of a substantially flat block member, a rotary driving source **514** which is connected to one end of the housing **512**, a rod cover (end block) **516** which is arranged while being separated by a predetermined distance from the housing **512** on the side opposite to the side on which the rotary driving source **514** is connected, and a feed screw shaft **518** which transmits the rotary driving force of the rotary driving source **514** by a coupling member as described later on.

The rotary driving source **514** is appropriately constructed by a servo motor including, for example, a brush-equipped DC motor, a brushless DC motor, and a stepping motor. A linear motor such as a solenoid may be used as the rotary driving source **514**.

The electric actuator **511** further includes a pair of guide rods **520***a*, **520***b* which are arranged in parallel with the feed screw shaft **518** interposing therebetween, which have first ends connected to the housing **512** by first screw members **519***a*, **519***b* (see FIG. **28**), and which have second ends connected to the rod cover **516** by second screw members **521***a*, **521***b* (see FIG. **28**), a piston **522** which is displaceable along the pair of guide rods **520***a*, **520***b* under the driving force transmitted by the feed screw shaft **518**, a hollow cylindrical piston rod **524** which penetrates through the rod cover **516** and which makes movement back and forth integrally with the piston **522**, and a socket **526** which is installed to the tip end of the piston rod **524** to close the hole.

The piston **522** and the piston rod **524** function as the movable member. It is preferable that an electroless nickel plating treatment is applied as a surface treatment for the feed screw shaft **518**. The feed screw shaft **518** may be commonly used as the motor shaft without using the coupling member **528**.

As shown in FIG. **28**, a first bearing **530***a* and a second bearing **530***b* are provided and juxtaposed respectively at the end of the feed screw shaft **518** disposed closely to the coupling member **528** in the housing **512**. The first bearing **530***a* and the second bearing **530***b* are retained by a first bearing holder **532***a* and a second bearing holder **532***b*.

A first end damper **536***a*, which has a through-hole **534** for allowing the feed screw shaft **518** to penetrate therethrough, is retained at the end of the housing **512** which faces the piston **522**. As shown in FIG. **30**, the first end damper **536***a* integrally comprises a cylindrical section **538** which has a predetermined wall thickness, and a flange section **540** which is diametrally expanded slightly in the radially outward direction as compared with the outer diameter of the cylindrical section **538**.

In this arrangement, the flange section **540** of the first end damper **536***a* is fastened by an annular recess **542** of the housing **512**. Accordingly, the first end damper **536***a* is retained in a state in which a part (end) of the cylindrical section **538** protrudes toward the piston **522** by a predetermined length from the end surface of the housing **512**.

A second end damper **536***b* and a bush **544** are provided on the inner wall of the rod cover **516** through which the piston rod **524** penetrates. The second end damper **536***b* has the same shape as that of the first end damper **536***a*. A flange section **540** is fastened by an annular recess **546** of the rod cover **516**. Accordingly, the second end damper **536***b* is retained in a state in which a part (end) of a cylindrical section **538** protrudes toward the piston **522** by a predetermined length from the end surface of the rod cover **516**.

It is preferable that each of the first end damper **536***a* and the second end damper **536***b* is formed of an elastic member such as urethane rubber.

As shown in FIG. **29**, the piston **522** includes a through-hole **548** having a substantially elliptical vertical cross section formed at a central portion thereof to penetrate in the axial direction, and a pair of lightening holes **550***a*, **550***b* which are formed on the both sides of the through-hole **548** in order to reduce weight. The piston **522** is integrally formed of, for example, a metal material such as aluminum. A substantially cylindrical sliding nut **552**, which has a screw hole **550** into which the feed screw shaft **518** is screwed, is inserted into the through-hole **548** of the piston **522** so that the sliding nut **552** is capable of making sliding movement in the axial direction of the feed screw shaft **518**.

In this arrangement, the sliding nut **552** and the piston **522** are provided relatively slidably in the axial direction of the feed screw shaft **518**. Further, the piston **522** is prevented from rotating in the circumferential direction by a pair of flat surface sections **554***a*, **554***b* which are formed on the outer circumferential surface of the sliding nut **552**.

A pair of annular piston dampers **556***a*, **556***b* as shown in FIG. **31** are installed to annular recesses at the both ends of the sliding nut **552**. The pair of piston dampers **556***a*, **556***b* are provided to protrude by predetermined lengths in the axial direction from the end surfaces of the sliding nut **552**.

In this arrangement, each of the piston dampers **556***a*, **556***b* has a pair of flat surface sections **557***a*, **557***b* formed on the outer circumference thereof (see FIG. **31**). The piston dampers **556***a*, **556***b* are formed to be flush with the vertical cross-sectional outer circumferential shape of the sliding nut **552**.

A connecting member **560**, which has a through-hole **558** for inserting the feed screw shaft **518** thereinto, is provided at one end of the piston **522** in the axial direction. The connecting member **560** comprises a first annular section **564** which has a first screw section composed of a male thread into which a female thread of the piston **522** is screwed, a second annular section **562** which has a second screw section composed of a male thread into which a female thread of the hollow piston rod **524** is screwed, and an annular flange section **566** which is provided between the first annular section **564** and the second annular section **562**. The first annular section **564**, the second annular section **562**, and the annular flange section **566** are formed in an integrated manner.

An annular member **568**, which has a male thread section formed on the outer circumferential surface into which the female thread section of the piston **522** is screwed, is connected to the other end of the piston **522** in the axial direction. The annular member **568** is provided to be flush with the end surface of the piston **522**.

In this arrangement, one piston damper **556***a*, which protrudes by a predetermined length from the end surface of the sliding nut **552**, is provided to make contact with the first annular section **564** of the connecting member **560**. The other piston damper **556***b*, which protrudes by a predetermined length from the end surface of the sliding nut **552**, is provided to make contact with the annular member **568**.

Therefore, the sliding nut **552** is retained in the piston **522** by the connecting member **560** and the annular member **568** which are fixed at the both ends of the piston **522**, except when the piston rod **524** abuts against the workpiece W and the impact is exerted on the piston rod **524**. The sliding nut **552** is displaceable integrally with the piston **522** in the axial direction under the screw engagement action with respect to the feed screw shaft **518**.

It is preferable that the pair of piston dampers **556***a*, **556***b* are formed of elastic members such as urethane rubber in the same manner as the first and second end dampers **536***a*, **536***b*.

Guide sections **570** (see FIG. **29**), each of which has a substantially circular arc-shaped cross section, are formed on the both side surfaces of the piston **522** extending perpendicularly to the axis. The piston **522** is interposed between the pair of guide rods **520***a*, **520***b*. A pair of plates **572***a*, **572***b* made of resin, which make line contact with the outer circumferential surfaces of the guide rods **520***a*, **520***b* and which extend in the axial direction of the guide rods **520***a*, **520***b*, are adhered to the guide sections **570**. By interposing the plates **572***a*, **572***b* made of the resin material between the piston **522** and the guide rods **520***a*, **520***b* each of which is made of the metal material, it is possible to reduce the sliding resistance.

The load is desirably absorbed by the pair of guide rods **520***a*, **520***b* in any one of a case in which the load is applied to the piston **522** in the radial direction and a case in which the load is applied to the piston **522** in the rotational direction. When the load is applied in the rotational direction, the pair of guide rods **520***a*, **520***b* function to stop the rotation.

As shown in FIG. **35**, the driver **18***a* has a casing **121** provided with a plurality of fins **119** protruding from a broad side surface. A plurality of control terminals **123**, which are electrically connected to the controller **20** via a cable, are provided at an upper portion of the casing **121**. Those provided at lower portions of the casing **121** are an unillustrated power source terminal which is connected to the power source **523** via a cable, and an unillustrated output terminal for the rotary driving source which is connected to the rotary driving source **514**.

Those provided on a narrow width side surface of the driver **18***a* are a torque-setting trimmer **125** with which the rotational torque (thrust force) of the rotary driving source **514** can be arbitrarily set externally by regulating the angle of rotation in a predetermined direction by using, for example, a plus screwdriver, a plurality of display lamps **127***a* to **127***d* which are recognizable in accordance with the light emission of unillustrated LEDs, and a plurality of manual switches which make it possible to perform, for example, the test operation in accordance with the manual operation.

The manual switches include a PHASE direction-switching switch **129** which indicates two directions of the A-PHASE direction (elongating direction of the piston rod **524**) and the B-PHASE direction (shrinking direction of the piston rod **524**) in accordance with the ON/OFF operation, an ON/OFF switch **131** which energizes and deenergizes the driver **18***a*, and a SET switch **133** in which the initial setting is established when the switch is turned OFF and the external thrust force can be selected by using the torque-setting trimmer **125** when the switch is turned ON.

With the PHASE direction-switching switch **129**, the forward or backward movement of the piston rod **524** is reversed in some cases between the A-PHASE direction and the B-PHASE direction in relation to the unillustrated gear.

The control signal, which is introduced into the driver **18***a* from the controller **20**, is composed of a binary signal of ON/OFF.

The rotational speed of the rotary driving source **514** can be controlled by arbitrarily changing the application voltage, which is applied from the power source **523** to the driver **18***a*, by using, for example, an unillustrated resistor, a transformer, or an internal circuit, or by incorporating the rotary driving source **514** into an unillustrated bridge circuit to provide an electronic governor (not shown) for feeding back the unbalanced voltage of the bridge circuit.

A flange **137**, through which attachment holes **135** are formed, is formed on a side surface opposite to the narrow width side surface on which the manual switches and other components are provided as described above.

The other portions of the driver **18***a* are constructed in the same manner as the driver **18** shown in FIG. **1** (see FIG. **2**), and detailed explanations thereof will be omitted.

The control system **10***a*, into which the driver **18***a* according to the modified embodiment is incorporated, is basically constructed as described above. Next, its operation, function, and effect will be explained.

At first, the direction instruction signal (binary signal) is introduced into the driver **18***a* from the controller **20**. The driver **18***a* switches the polarity of the voltage based on the direction instruction signal. Accordingly, the rotation direction of the rotary driving source **514** is switched to the forward or backward direction. The voltage, which corresponds to the current supplied from the direction-switching means **34** to the rotary driving source **514**, is inputted into the current amplifier/limiter **36**.

The current amplifier/limiter **36** converts the voltage outputted from the direction-switching means **34** into the corresponding current which is supplied to the rotary driving source **514**. Accordingly, the rotary driving source **514** is driven and rotated in the predetermined direction, and the rotary driving force of the rotary driving source **514** is transmitted to the feed screw shaft **518** by the coupling member **528**.

The feed screw shaft **518**, which is rotated in the predetermined direction, is screwed to the screw hole **550** of the sliding nut **552** which functions as the feed nut. Accordingly, the sliding nut **552** and the piston **522** are displaced in the axial direction integrally with the piston rod **524** by the guidance of the pair of guide rods **520***a*, **520***b*. Therefore, the piston rod **524** is displaced toward the outside integrally with the piston **522**, and the piston rod **524** arrives at the stroke end, thereby pressing the unillustrated workpiece to the predetermined position.

As shown in FIG. **32**, when the piston **522** does not arrive at both stroke ends, and the operation for pressing the workpiece W is performed at an intermediate position therebetween, then the impact is transmitted to the piston **522** via the socket **526** which abuts against the workpiece W, the piston rod **524**, and the connecting member **560**.

In this situation, the end portion of the piston damper **556***a*, which contacts the connecting member **560**, is deformed as shown in FIG. **33**, and thus the impact is received. Further, the sliding nut **552**, which is provided in the piston **522**, slides slightly in the axial direction of the feed screw shaft **518** with respect to the piston **522** (see two-dot chain lines shown in FIG. **33**). Accordingly, the impact is desirably absorbed.

In other words, the piston **522** and the connecting member **560**, which are connected to each other, are provided displaceably in the axial direction of the feed screw shaft **518** in response to the impact applied to the piston rod **524**. The slight displacement of the piston **522** and the connecting member **560** is absorbed by the piston damper **556***a* which has elasticity and which is installed to the end of the sliding nut **552**. Accordingly, the impact is desirably absorbed.

In this situation, the sliding nut **552** is not displaced in relation to the feed screw shaft **518**, because the sliding nut **552** is screwed to the feed screw shaft **518**. Further, the impact is prevented from being transmitted to the screw engagement portion of the sliding nut **552** and the feed screw shaft **518**. Accordingly, it is possible to desirably protect the screw engagement portion of the sliding nut **552** and the feed screw shaft **518**.

Therefore, even when the workpiece W is pressed against the piston rod **524** at the intermediate position between both stroke ends, the impact, which is applied to the piston rod **524**, is smoothly absorbed by the relative sLiding displacement between the piston **522** and the sliding nut **552** and the elastic piston damper **556***a*. Therefore, it is possible to avoid deterioration of the durability of the electric actuator **511**.

Further, when the impact is caused at the forward movement stroke end of the piston rod **524**, the impact is absorbed more preferably, because of the synergistic buffering effect of the piston damper **556***a* and abutment of the annular flange section **566** of the connecting member **560** against the second end damper **536***b* (see FIG. **34**).

Similarly, when the impact is generated at the backward movement stroke end of the piston rod **524**, the impact is absorbed more preferably, because of the synergistic buffering effect of the piston damper **556***b* and abutment of the end surface of the annular member **568** and the piston **522** against the first end damper **536***a* (see FIG. **28**).

As described above, the buffering mechanism is provided, which includes the pair of piston dampers **556***a*, **556***b* provided for the piston **522**, and the first and second end dampers **536***a*, **536***b* provided for the housing **512** and the rod cover **516**. Accordingly, the impact on the piston **522** can be preferably buffered at any arbitrary position including both stroke ends and the intermediate position therebetween.

The electric actuator can be used as an actuator driven by the motor usable in the same manner as the air cylinder even in an environment in which compressed air is absent or compressed air cannot be used.

In this case, the phrase "in the same manner as the air cylinder" refers, for example, to the fact that the electric actuator is driven in accordance with the ON/OFF control, no controller is required, it is possible to press the piston **522**, the electric actuator can be driven without any sensor, and it is possible to control the speed and the thrust force.

Further, the predetermined rigidity is maintained by the pair of parallel guide rods **520***a*, **520***b* without the need for a rigid body. Accordingly, the number of parts is decreased, the production cost is reduced, and it is possible to realize a light weight.

Furthermore, an impact absorber (damper) is generally arranged at a portion where parts collide with each other in the driving apparatus. However, when the property, size, and displacement amount of the damper are set so that the impact value upon collision is not more than 5 G, preferably not more than 2 G, then it is possible to improve the durability of the damper, thereby improving the durability of the electric actuator. The strength of each part can be reduced by suppressing the impact value, and hence it is possible to reduce size and weight of the apparatus.

As for the method for producing the housing **512** and the rod cover **516**, it is preferable to use, for example, integrated molding based on aluminum die casting, plate deep drawing, or stacked steel plates integrally formed by stacking a plurality of steel plates.

As for the feed screw shaft **518**, it is preferable to use, for example, a slide screw shaft made of resin, a slide screw shaft made of metal, a ball screw shaft, or a timing belt suspended between pulleys.

When the workpiece W is pressed to a predetermined position by the piston rod **524** and a high load is applied to the rotary driving source **514** after the piston **522** and the piston rod **524** arrive at the stroke end, the rotation of the drive shaft of the rotary driving source **514** is stopped and restricted. In this situation, the torque, which is outputted from the drive shaft of the rotary driving source **514**, is proportional to the current applied to the rotary driving source **514**. Therefore, when the drive shaft is restricted, the current (overcurrent), which is not less than the predetermined current value, is applied to the rotary driving source **514**. When the overcurrent is generated, the rotary driving source **514** may undesirably burn out.

Accordingly, the detection signal, which is fed from the current sensor **38** for detecting the current to be supplied to the rotary driving source **514**, is introduced into the current amplifier/limiter **36** via the detection line **41**. The current amplifier/limiter **36** compares, by the comparing means **44**, the preset reference current I_{MAX} stored in the storage means **42** with the detection signal supplied from the current sensor **38**. Further, the current, which is to be supplied to the rotary driving source **514**, is limited by the current limit means **46** so that the current does not exceed the reference current I_{MAX} (see FIG. **2**).

The current value, which is used when the rotary driving source **514** is controlled, is limited, for example, to not more than 0.6 A when the drive shaft of the rotary driving source **514** is stopped and restricted, and not more than 0.2 A during the driving state with no load. Accordingly, the rotary driving source **514** is able to have a long service life.

As described above, in the driver **18***a* of the present embodiment, the value of the current supplied to the rotary driving source **514** is monitored by the current sensor **38**, and the current amplifier/limiter **36** is used to limit the current applied to the rotary driving source **514** to be not more than the reference current I_{MAX}. As a result, even when the high load is applied to the rotary driving source **514**, and the drive shaft of the rotary driving source **514** in the ON state is stopped and restricted, the current supplied to the rotary driving source **514** is limited to be not more than the preset reference current I_{MAX}. Therefore, it is possible to prevent the rotary driving source **514** from burning out by the overcurrent. It is a matter of course that the torque, which is proportional to the application current, can be limited by limiting the application current to be supplied to the rotary driving source **514**.

Next, a modified embodiment of the electric actuator is shown in FIGS. **36** to **38**. The same constitutive components as those of the electric actuator **511** shown in FIG. **27** are designated by the same reference numerals, and detailed explanation thereof will be omitted.

An electric actuator **580** according to the present modified embodiment is different from the electric actuator **511** in that the pair of guide rods **520***a*, **520***b* is not provided, a lengthy cylindrical tube **586** is provided to connect a cylindrical housing **582** and a stepped cylindrical rod cover **584**, and a piston **590** is accommodated in a hollow section **588** of the tube **586**.

Those secured to recesses of the outer circumferential surface of the piston **590** are a pair of guide plates **592***a*, **592***b* each of which is made of a resin material and which extend in the axial direction, and a pair of magnets **594***a*, **594***b* each of which has a semicircular form with a circular arc-shaped cross section.

In this arrangement, only the pair of guide plates **592***a*, **592***b* slides along flat guide surfaces **596***a*, **596***b* formed on the inner wall of the tube **586**. Therefore, the piston **590** is guided and the tube **586** is prevented from rotating in the circumferential direction. A predetermined clearance **598** is provided between the outer wall of the piston **590** and the inner wall of the tube **586** at a portion except for the guide plates **592***a*, **592***b* (see FIG. **38**).

The sliding nut **552** having the same shape is installed slidably in the piston **590** in the same manner as the electric actuator **511** described above. The sliding nut **552** is retained by a connecting member **600** which is connected to one end of the piston **590** and a C-clip **602** which is installed to the other end of the piston **590**.

One or more of sensors including, for example, proximity sensors and photomicrosensors is attached to a predetermined portion on the outer circumferential surface of the tube **586** by an unillustrated band. The magnetic fields of the magnets **594***a*, **594***b* are detected by a sensor (not shown) installed to the tube **586**. Accordingly, the position of the piston **522** is detected.

The functions of the pair of piston dampers **556***a*, **556***b* and the first and second end dampers **536***a*, **536***b* are the same as those of the electric actuator **511**, and detailed explanation thereof will be omitted.

In the present embodiment, although only the electric actuator of the rod type, in which the piston rod **524** expands and contracts, is disclosed, there is no limitation thereto. It is a matter of course that the present invention is also applicable to the electric actuator of the slide table type used by connecting an unillustrated slide table to the piston **522**.

When the electric actuator of the slide table type is adopted, the rod type can be easily changed to the slide table type by detaching the piston rod **524** from the piston **522** and by using another unillustrated rod cover in which the hole for allowing the piston rod **524** to penetrate therethrough is closed.

It is preferable that the control system **10***a* is incorporated with an apparatus which automatically switches speed reducing ratio when the load, which exceeds the predetermined torque, is applied to the rotary driving source **514**. Since, the speed of rotation of the rotary driving source **514** can be controlled depending on the load.

FIG. **39** shows characteristics of the torque and the speed obtained when only the rotary driving source **514** is provided and when the rotary driving source **514** is equipped with an apparatus for automatically switching speed reducing ratio. As shown in FIG. **39**, a torque with respect to a speed can be controlled easily when the rotary driving source **514** is equipped with the apparatus for automatically switching speed reducing ratio as compared with the case in which only the rotary driving source **514** is provided.

FIG. **40** shows a perspective view illustrating a driver manifold for direction control.

A plurality of drivers **18** for direction control, which are connected to a plurality of electric actuators **511** (electric cylinders), are stacked to constitute the manifold. In this arrangement, the plurality of drivers **18** for direction control are bus-coupled by the electric signal (for example, a serial signal) via unillustrated connectors. It is preferable that a power source-generating unit **601** is additionally provided to generate, for example, AC 100 to 200 V or DC 24 V which is to be supplied. The plurality of drivers **18** for direction control are detachably stacked by a lengthy rail member **603**. It is preferable that fans **604** are provided for the drivers **18** and the power source-generating unit **601**.

Next, FIG. **41** shows a motor driver characteristic in relation to the number of revolutions and the torque (current value). As shown in FIG. **41**, when the current is limited, then the motor (rotary driving source **514**) can be prevented from burning out, and it is possible to limit the torque. FIG. **42** shows a load-speed control characteristic in relation to the relationship between the number of revolutions and the torque (current value). When the current value is set corresponding to the load, the current limits (for example, Limits 1 to 4) are set. In this case, the load is based on, for example, the generator and the internal viscous resistance.

In the foregoing description, the motor includes, for example, at least DC motors, coreless motors, brushless DC motors, linear motors, and voice coil motors.

The drivers **18**, **18***a*, which are direction control apparatuses incorporated into the control systems **10**, **10***a*, correspond to the open network (for example, the device net, PROFIBUS, CAN, and Inthernet) respectively. It is possible to form a network together with other control apparatuses. For example, remote operation and diagnosis can be performed via the internet or the portable terminal (including portable telephones) by using the network.

Further, a direction control apparatus of the composite type body makes it possible to control a plurality of motors by using one direction control apparatus. The direction control apparatus can be driven, for example, by a battery and a cell (including a fuel cell) instead of an ordinary power source.

Although certain preferred embodiments of the present invention have been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.

What is claimed is:

1. A control system for an electric actuator having a movable member which is displaceable under a rotary driving action of a rotary driving source, said control system comprising:

said electric actuator having said movable member which makes linear reciprocating motion under said driving action of said rotary driving source;

a driver which energizes and deenergizes said rotary driving source equipped for said electric actuator; and

a controller which outputs a direction instruction signal to said driver,

wherein said electric actuator includes an actuator body, said rotary driving source which is connected to one end of said actuator body, a pair of guide shafts which extend in parallel between said actuator body and an end block, a feed screw shaft which is connected to a drive shaft of said rotary driving source, and said movable member which makes said linear reciprocating motion along said pair of guide shafts by screwing said feed screw shaft;

and said driver is provided with a current-detecting means which detects a current supplied to said rotary driving source, a comparing means which compares a detection signal from said current-detecting means with a preset reference current, and a current limit means which, without cutting off supply of said current to said rotary driving soure, limits said current supplied to said rotary driving source so that said current does not exceed said reference current when a load is applied to said rotary driving source while maintaining an energized state and said drive shaft of said rotary driving source is stopped and restricted.

2. The control system according to claim **1**, wherein

said movable member of said electric actuator includes a piston which is displaceable along a pair of guide rods under a driving force transmitted via said feed screw shaft, and a hollow cylindrical piston rod which penetrates through said end block and which makes movement back and forth integrally with said piston;

a sliding nut, which has a screw hole for being screwed to said feed screw shaft, is internally fitted to a through-hole which is formed in an axial direction of said piston; and

a pair of piston dampers formed of an elastic material are provided at both ends of said sliding nut in an axial direction in a state in which said pair of piston dampers protrude by predetermined lengths from end surfaces of said sliding nut.

3. The control system according to claim **2**, further comprising a pair of first and second end dampers which are arranged in said actuator body and which absorb impact at stroke ends of said piston rod.

4. The control system according to claim **1**, wherein

a torque-setting trimmer which sets a rotational torque of said rotary driving source from outside, a plurality of display lamps, and a plurality of manually operatable switches are provided on a narrow side surface of said driver; and said manual switches include a PHASE direction-switching switch which performs switching between an elongating direction of said movable member and a shrinking direction of said movable member.

5. The control system according to claim **1**, wherein a mechanism for switching speed reducing ratio is interposed between said rotary driving source and said feed screw shaft, said mechanism for switching speed reducing ratio being provided with a sun gear, a planet gear, and an internal gear each of which is composed of helical gear.

6. The control system according to claim **1**, wherein said driver has a casing which includes a plurality of fins protruding from a broad side surface.

7. The control system according to claim **1**, wherein a plurality of said drivers are continuously stacked to form a manifold.

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